DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-77-28

UNDERGROUND BIOMASS DYNAMICS AND SUBSTRATE SELECTIVE PROPERTIES OF ATLANTIC COASTAL SALT MARSH PLANTS

by

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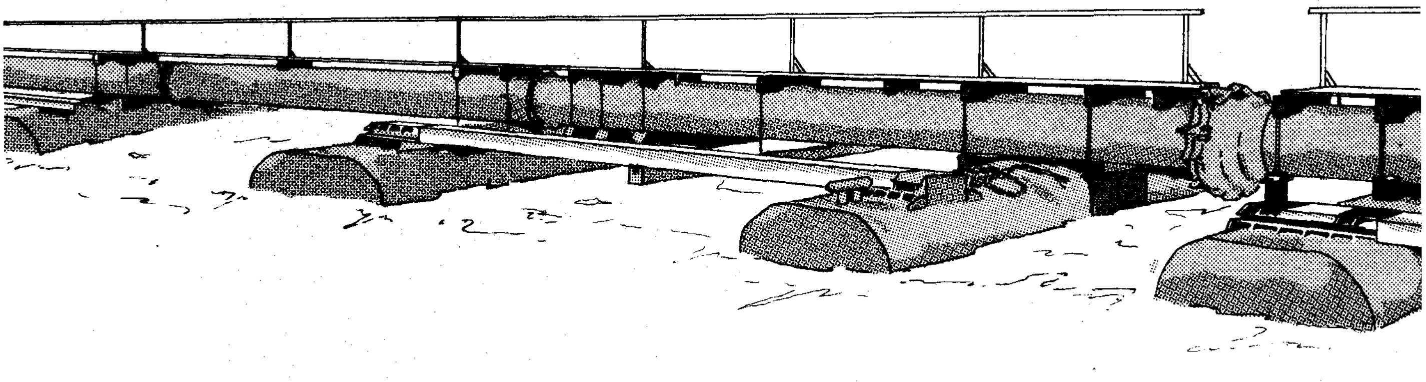

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SUBJECT: Transmittal of Technical Report D-77-28

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1. The technical report transmitted herewith represents the results of one of the research efforts (work units) under Task 4A (Marsh Development) of the Corps of Engineers' Dredged Material Research Program (DMRP). Task 4A is a part of the Habitat Development Project of the DMRP and is concerned with developing, testing, and evaluating the environmental, economic, and engineering feasibility of using dredged material as a substrate for marsh development.

2. An intensive study of the underground portion of selected salt marsh species was conducted under Work Unit 4A04A2. The purpose of this research was to describe the characteristics of natural marsh substrates and to define the interactions between marsh plant growth and each characteristic of the substrate. The most useful combination of parameters for predicting marsh plant success was found to be soil texture, pH, salinity, and total nitrogen. Criteria for determining when the soil conditions in a man-made marsh approximate those of natural marshes have also been included in this report.

3. This work unit is one of several research efforts designed by the DMRP to document marsh productivity and the factors which influence that productivity. Closely related work units are 4A04A1 and 4A04B, which address the productivity of minor marsh species along the Atlantic and Gulf coasts, respectively; 4A04, in which a simulation model to predict salt marsh productivity was developed; and 4A20, a less intensive effort that will provide a general evaluation of salt marsh productivity on the Pacific coast of the United States. Additional supportive and comparative data will be forthcoming with the final analysis of the results of field studies at Windmill Point, Virginia, (4A11); Buttermilk Sound, Georgia, (4A12); Apalachicola, Florida, (4A19); Bolivar Peninsula, Texas, (4A13); Pond No. 3, California, (4A18); and Miller Sands, Oregon, (4B05).

Together these research products provide the Corps with a comprehensive basis for sound management decisions regarding habitat development on dredged material and disposal in natural marsh habitats.

JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director

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As part of the U. S. Army Corps of Engineers' comprehensive Dredged Material Research Program, which is being conducted by the Environmental Effects Laboratory of the U. S. Army Engineer Waterways Experiment Station in Vicksburg, Mississippi, an intensive study of the dynamics of the underground portion of selected salt marsh plants along the U. S. Atlantic Coast was made. The plants studied included: Borrichia frutescens, Carex paleacea, Distichlis spicata, Eleocharis obtusa, Juncus gerardi J. roemerianus, Phragmites communis,

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20. ABSTRACT (Continued).

Salicornia virginica, _Spartina alterniflora_, _S. bakeri_, _S. cynosuroides_, _S. patens_, and _Sporobolus virginicus_.

The study provides information applicable to marsh development on dredged material, particularly methodologies that can be used for determining which marsh plants will be likely to do well on various kinds of dredged material and when a marsh, which has been established on dredged material, approaches natural conditions.

The overall study focuses on three major efforts: an investigation of underground biomass dynamics, characterization of soils supporting the salt marsh plants, and experimentation on the substrate selective properties of several of the marsh plants studied. The methods and results for the specific aspects of these three efforts are delineated in five self-contained sections of the report: underground biomass profiles and dynamics in Atlantic coastal marshes, comparison of some tidal marsh soils along the Atlantic Coast, response of salt marsh plant stands to a pulse of ammonium nitrate, salt marsh plant growth on three types of dredged material, and a bioassay approach to studying marsh plant root growth in natural soil and dredged material.

Findings of the studies indicate that in developing salt marsh on dredged material, five substrate problems should be considered: stability (dredged material texture and exposure to wave action); pH characteristics (pH in situ, in water, and in buffer); salinity characteristics (in situ, leacheable, desalination index); soil characteristics; and nutrients, of which nitrogen appears to be the key element. Depth of root penetration must also be considered when dredged material containing contaminants is used.

The report gives recommendations on the use of dredged material and plant species and emphasizes the advisability of a field bioassay prior to dredging. While it is not yet possible to predict with high probability the success of a specific plant on a specific dredged material in a specific salinity and under a specific tidal regime, the report shows that the most useful combinations of parameters in predicting marsh plant success are: soil texture, pH properties, salinity, and total nitrogen.

The appendixes were prepared on microfiche and are enclosed in an envelope in the back cover.

EXECUTIVE SUMMARY

This report summarizes work done on the dynamics of the underground portion of some of the salt marsh plants along the Atlantic coast of the United States, the characterization of soils in those plant stands, and experiments on the substrate selective properties of several of the plants.

The underground biomass profiles and dynamics study (Part II) involved year-long sampling programs in 18 stands of salt marsh plants in Georgia, Delaware, and Maine. Cores of the marsh were taken at monthly or bimonthly intervals and the cores sectioned into depth profiles (0-5 cm, 5-10 cm, 10-15 cm, 15-35 cm, and 35-55 cm for some plants) and the macro-organic matter (MOM - organic matter not passing a 1-mm sieve) separated by washing on a 1-mm sieve. THe MOM was dried and profiles and seasonal curves plotted from these data. Three types of profiles were found in the marshes. In the first the concentration of MOM was uniform with depth; the notable example of this type was creekbank *Spartina alterniflora* in the southern part of the coast. A second type had a high concentration at the surface which dropped with depth. Most species exhibited this type of profile. *Spartina patens*, *S. alterniflora* from the high marsh along the southern coast, and creekbank *S. alterniflora* from the northern range (Maine) are examples. The third type was seen where a large rhizome mat developed at 15-20 cm below the surface. This type of profile had a relatively low biomass at the surface, a higher biomass somewhat below the surface, and a low concentration below that. Spartina cynosuroides and Phragmites communis were typical examples. The information on the types of profiles present in the natural marsh will be useful in determining when the natural profile shapes and MOM concentrations have been achieved in marshes formed on dredged material. Since the underground MOM is important in stabilizing the dredged material, supplying microbes with organic and inorganic nutrients, and thus regulating nutrient exchange between the soil and the overlying water, achievement of the "natural situation" is of prime importance in marsh-creation projects.

The annual highs and lows of MOM biomass were used to calculate an annual increment, which can be considered a minimum annual production value. The values ranged from a low of 80 g C/m^2 for creekhead S. alterniflora in Maine to a high of 1690 g C/m^2 for Juncus gerardi in Maine. The mean for all stands measured was 654 g C/m^2. Since the average carbon content of the MOM was 35.3%, this corresponds to 1852 g dry weight/m^2 per year which is comparable to the usually reported aerial production for marsh macrophytes. The plants are therefore allocating a major portion of the photosynthate to the underground portion of the plant and the food web dominated by meiobenthic animals and soil microbes. The latter group is particularly important in determining the cycling concentrates in the water flowing over marshes.

As a measure of the relative activity of the total pool of macro-organic material in the soil, a turnover time was calculated by dividing the total macro-organic matter by the annual increment. While there are at least several pools with turnover times varying from days to centuries, the overall turnover gives a measure which can be used to estimate production when the quantity of macro-organic matter is known but there is no time for a yearlong study. The turnover time ranged from 18 months in two Georgia plant stands to 224 months for one in Maine. In the two instances where Maine values for a species could be compared to those from Georgia, the turnover time was less for the more southerly station. This probably reflected the slower microbial decay rates in the cooler climate. Thus most elements are bound to large particles of organic matter in the lower temperature climate. In Georgia and Maine where the turnover values for a single species were determined for two elevations, the time was less for the lower elevation. This probably resulted from greater microbial activity associated with more rapid flushing rates of water through the creekbank soils. The mineral composition of the underground portions of the plants is presented in Part II and Appendix B. This information can be used to determine if a planted marsh has the same elemental composition as a natural one.

Part III of the report describes soil profiles in plant stands in marshes in Georgia, Delaware, and Maine. These descriptions give data which are useful in classifying soils associated with various marsh plants along the Atlantic coast and would be useful in evaluating to what extent a marsh developed on dredged material resembles a natural marsh.

In addition to the field descriptions, data are presented which describe the physical and chemical aspects of the various horizons.

The most important of these for predicting the success dredged material would have in supporting a given plant are the salinity characteristics (salinity, desalination index), pH properties (pH *in situ*, pH in water, and pH in buffer), and total nitrogen (N) which can be obtained either directly or by correlation with C content. Also presented are data on leachable ions. These ionic data were obtained on dried soils rather than those kept moist and under anaerobic conditions. This was done although the anaerobic moist condition represents the natural condition under which these soils exist. The authors feel that the extractions under any conditions do not represent the actual conditions to which roots are exposed. Because roots are continually removing nutrients, the flux rate rather than the pool size measured by extraction is the most important factor to consider. Additionally, no chemical extraction can duplicate the roots' capability to remove nutrients. Further, it is doubted that District Engineers would have facilities to take and ship soil samples under anaerobic conditions and have labs available to analyze them under those conditions; therefore, the soils were handled as typically done by agriculture researchers. District Engineers will be able to handle dredged material in this fashion and have it analyzed in local state college agricultural experiment stations. The success agriculture researchers have had in predicting yields and making recommendations regarding species success and advising fertilizer and lime requirements has been based on correlations between soils tests and field experiences rather than absolute tidal concentration of nutrients. In this study, data collection was begun for eventual prediction capability. The data represent natural soils and three widely differing types of dredged material from Georgia.

Part IV reports on the response of marsh plant stands to a pulse of nitrogen. In Georgia, _Salicornia virginica_ and _S. alterniflora_ responded to a 150 kg/ha pulse of N (as NH_4NO_3) by an increase in biomass. Although no biomass change was noted, the _Sporobolus virginicus_ plants were higher in nitrogen than the control plants. _Borrichia frutescens_ had a higher chlorophyll concentration, although no other response was detected in stands of _Distichlis spicata_, _S. cynosuroides_, or _S. patens_. In Delaware a positive biomass response was obtained in stands of _J. gerardi_ and _S. virginica_. Although no biomass differences were measured, the treated _D. spicata_ plants were significantly higher in chlorophyll than were the control plants. None of the plant stands in Maine responded to added N. This might be expected in view of the high levels of extractable NH_4 found in the soil (Part III). No differences in ability to remove N from various application depths to 35 cm were noted.

Part V of this report deals with tests of marsh plant growth on three types of dredged material in the greenhouse and in field test sites. Specific recommendations regarding the growth of species or substrates tested are given in this section. The synthesis of this and the previous section is that it is not possible with the present state of knowledge to predict with high probability the success of a specific plant on a specific dredged material in a specific salinity and in a specific tidal inundation regime. Therefore, a bioassay is proposed to be made by District Engineers using a series of modified buckets to check plant performance at specific sites prior to attempting marsh establishment on dredged material.

Part VI deals with bioassay techniques designed to assess root growth in specific dredged material. The method is presented as are specific results of several experiments. In a test with a freshwater plant (*Eleocharis obtusa*), the best growth was in a sandy dredged material of low salinity. Approximately 1/3 as much growth occurred in two freshwater muds. Growth in a saline sand, a saline silty clay, and a brackish mixture of sand and silty clay produced only 1/7 the growth obtained with low salinity sand.

Spartina patens root growth is enhanced when whole plants are grown under cooler rather than warmer environmental conditions. *Spartina patens* and *S. alterniflora* root growth did not differ under drained or saturated conditions when a sand substrate was used. Equal growth was obtained with either 10 or 20‰ salinity. Growth in natural soil was 6-12 times greater than in the sandy saline dredged material tested. When the soil temperature was lowered while air temperature remained high, three species of *Spartina* (*S. alterniflora*, *S. bakeri*, and *S. patens*) showed reduced aerial and underground growth. This indicates the increased root growth at low temperatures seen in two earlier experiments where whole plants were subjected to the temperature differences was either a whole plant effect or an effect on the shoots alone.

In drawing conclusions and recommendations from these studies, there appear to be five substrate problems which should be considered when planning to create a salt marsh.

1. Stability. Two factors are important here: exposure to wave action and dredged material texture. Although this problem was not addressed directly in this study, some of the results are pertinent. The development of a large root underground system (roots and rhizome) is important. Particularly effective in this respect are *S. patens*, *D. spicata*, and *S. virginicus*.

2. pH characteristics. Basic to this problem is the cat clay characteristic of soils containing sulfides. In this situation, reduced forms of sulfur oxidize when the sediment is exposed to air and the resulting strong acid causes a sharp drop in pH. Examination of pH in situ, pH after drying, and pH in buffer can be used to predict the probable extent of cat clay development.

3. Salinity characteristics. Coupled with salinity tolerance is drought tolerance. In salt marshes, drought conditions are almost always coupled with high salinity situations. If dredged material is placed in subtidal areas, the drought and salinity conditions can be regulated by the final elevations of the created island. In cases where dredged material is placed on existing marsh, salinity and drought conditions will often be accentuated because of the high elevation. The plants found to be most tolerant of these conditions are *S. patens*, *D. spicata*, *S. virginicus*, and *S. virginica*.

4. Elevation (balance of air and water). The elevation factor is complex, involving salinity and pH characteristics as well as other factors. Since dredged material placed low in the intertidal range will be inundated more frequently and for longer periods than that placed near the upper boundary of the tides' influence, different soil characteristics will develop along the gradient. Soil pH will usually be lower in the upper zone because of oxidation of sulfur forms in the better drained soils. The pH drop may be dramatic and prevent plant growth with certain collections of sulfur ion species. Salinity will be more stable where tidal water frequently flushes the soil. In the upper reaches, evapotranspiration will tend to concentrate salt and fluctuations will be too great for many species to tolerate. Soil structure may also be influenced

by salt accumulation resulting in the reduced percolation of rainwater. The authors believe the best evaluation of this complex factor can be made by a bioassay on the site.

5. Nutrients. As with many ecosystems, N seems to be a key element. Only in sandy dredged material does it seem probable that N will be the limiting factor to the growth of the plants.

When dredged material containing contaminants such as heavy metals and pesticides is used for marsh development, the depth to which roots penetrate the substrate must be considered. The studies reported herein show that *S. virginica* and *S. virginicus* are shallow-rooted plants (< 35 cm); *S. alterniflora* at high elevations, *D. spicata*, and *S. patens* are medium in rooting depth (35-55 cm); and *S. alterniflora* plants at low elevations, *J. roemerianus*, and *P. communis* are deep-rooted (> 55 cm).

PREFACE

This is a report of research initiated in June 1973 for the U. S. Army Engineer Waterways Experiment Station (WES) under Contract No. DACW39-73-C-0110 as part of the Dredged Material Research Program (DMRP), Habitat Development Project (HDP) with University of Georgia Marine Institute. The DMRP is sponsored by the Office, Chief of Engineers (DAEW-CWO-M), and is assigned to the WES under the Environmental Effects Laboratory (EEL).

This report was prepared by John L. Gallagher, F. Gerald Plumley, and Paul L. Wolf.

In addition to the authors of the volume, many others contributed significantly to the massive sampling and analysis program. Especially significant was the contribution of Dr. Robert J. Reimold whose complementary work on the aerial portion of the salt marsh plants appears in another volume. Efforts of the following are much appreciated: Rick A. Linthurst, Owen M. Ulmer, Jr., Edward J. Selker, Patrick C. Adams, William J. Pfeiffer, Ann O. Fornes, Sarah E. Robinson, Robert Wilkes, Helen D. Walker, Allyson S. Linthurst, Jacquelyn B. Ulmer, Christine M. Mellinger, Victoria C. Wray, Hannah D. Brown, Shirley A. Walker, Gregory A. Kramer, Dianne H. Adams, Cathy J. Selker, Mattie L. Banks, Harold Church, Ronald Smith, Leo J. Cotnoir, John Ferwerda, Richard Keck, Denise M. Seliskar, Thomas C. Pearson, and Phyllis Hawkins.

The study was conducted under the supervision of Drs. C. J. Kirby and H. K. Smith, Project Managers for the HDP, and under the general supervision of Dr. John Harrison, Chief, EEL. HDP Botanists, Dr. Luther Holloway and 1LT Terry Huffman monitored the study.

Directors of the WES during preparation of this report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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PART I: INTRODUCTION

Among the important considerations in planning the development of a salt marsh on dredged material is the substrate selective properties of the prospective species to be planted. A number of questions arise:

1. What are the characteristics of the dredged material?
2. How do these characteristics change when the dredged material is placed at various elevations in the intertidal zone?
3. How do the predicted substrate conditions correlate with those found in the soils supporting natural stands of species being considered for planting on the site?
4. Based on root system dynamics in natural marshes, what would be a minimum estimate of root system productivity in natural dredged material marshes?
5. Which marsh plants will form dense root mats?
6. What rooting depth is characteristic of the various plants?

The approach to answering the questions about the substrate selective properties of the plants was to:

1. Characterize the natural underground productivity and organic matter deposition system by examining the dynamics of the underground macro-organic matter in natural stands of marsh plants in Georgia, Delaware, and Maine. Methods were developed

which would enable others to conduct similar evaluations on marsh species not included in this study. The results of these studies are detailed in Part II of this report.

2. Characterize the natural soil systems under which the marsh plants in Georgia, Delaware, and Maine grow. Methods were selected which could be followed by District Engineers in these local situations. This study was intended as a beginning of a data set, which would allow correlation of marsh soil and dredged material parameters with observed plant establishment success and productivity measurement. These initial studies are summarized in Part III of this report.

3. Since high marsh S. alterniflora responded to added nitrogen in Delaware, North Carolina, and Georgia, it was hypothesized that the productivity of these and other marsh plants may be enhanced at various sites along the coast. These results give an indication of the nutritional state of the natural plants on soils with certain nutrient characteristics. This information will be valuable in predicting the probable response of the plants to fertilizer added to plants being established on dredged material. Part IV of this report contains the results of a study of plant stands along the western coast of the Atlantic Ocean.

4. There are many types of dredged material, many species of plants, and even more sets of environmental conditions under which they may be placed. Since it was not practical to test

all combinations, it was felt that bioassay procedures should be developed for growing plants on a variety of dredged material under various conditions. Both a field and a laboratory bioassay test were developed and tested which are described in Parts V and VI of this report. In addition to the methodology, these sections report on several practical problems that were examined using dredged material from five sites.

PART II: UNDERGROUND BIOMASS PROFILES AND DYNAMICS IN ATLANTIC COASTAL MARSHES

Introduction

Many studies of aerial plant parts have been reported in the literature, but the dynamics of the underground portions of salt marsh plants have received little attention. Most of the fixed carbon reserves of salt marshes are, however, in the soils (Gallagher, 1974; Valiela et al., 1976). Almost all of the macro-organic matter (retained on a 1-mm sieve) in Georgia salt marshes is identifiable as root, rhizome, or stem base material.

The dynamics of the macro-organic matter (MOM) pool is the net result of numerous processes. Those which add to the pool are root, rhizome, and stem base growth, as well as storage of photosynthate. Translocation to aerial structures, physical disintegration, and microbial decay remove material from the pool. The study was designed to examine the dynamics of the MOM carbon pool in salt marshes along the eastern coast of the United States. This knowledge is important to understanding soil development and stability, microbial dynamics, and ecosystem energetics in the various marsh types along the latitudinal gradient. Knowledge of the underground biomass in these natural marshes can act as a guide to evaluating the maturity of a developing marsh on natural substrate or dredged material.

Methods

A sampling program, described in Table 1, was conducted from March 1972 to April 1975. Study sites were chosen in Georgia, Delaware, and Maine since they represented the extremes and a central location where marshes are abundant along the United States Atlantic coast. The accessibility of the marsh and availability of laboratory facilities were of secondary consideration in choosing site locations. In Georgia, areas near the University of Georgia Marine Institute were selected. _Spartina cynosuroides_ was sampled on a small island near the mouth of the Altamaha River where water salinity was usually less than 3‰. _Borrichia frutescens_, _Distichlis spicata_, _Iva frutescens_, _Spartina patens_, and _Sporobolus virginicus_ were sampled in marshes developed along creeks behind the dune complex on the eastern side of Sapelo Island. _Spartina alterniflora_, _Juncus roemerianus_, and _Salicornia virginica_ were studied in the Duplin River Estuary on the western side of Sapelo Island. All of the plants in Delaware were sampled in Canary Creek Marsh near Roosevelt Inlet in Lewes, Delaware. The Maine study sites were in Franklin County. _Juncus gerardi_ and creekbank _S. alterniflora_ were collected along Northeast Creek west of Salisbury Cove, and _S. patens_ and creekhead _S. alterniflora_ were sampled in marshes on the south side of Hoy Bay near its head.

Samples were collected and processed for macro-organic matter content by the methods described by Gallagher (1974). An aluminum coring device was used to collect underground organic matter samples, which were washed free of the mineral and micro-organic matter over a 1-mm

Table 1

Underground Biomass Sampling Program in Atlantic Coastal Marshes of the United States

Plant	Location and Sampling Period	Number of Cores	Sampling Intervals (wks.)
Borrichia frutescens	GA(8/73-9/74)	5	8
Distichlis spicata	GA(8/73-9/74)	5	8
	DL(8/73-9/74)	5	8
Juncus gerardi	DL(8/73-9/74)	5	8
	ME(6,8,9/74;4/75)	5	8
Juncus roemerianus	GA(3/72-3/73)	6	4
*Phragmites communis**	DL(10/73-9/74)	3+3**	8
Salicornia virginica	GA(8/73-9/74)	5	8
	DL(10/73-12/74)	5	8
Spartina cynosuroides	GA(10/73-1/75)	3+3**	8
Spartina alterniflora			
Creekbank	GA(3/72-2/73)	6	4
	ME(6,8,9/74;4/75)	5	8
Creekhead	ME(6,8,9/74;4/75)	5	8
High marsh	GA(3/72-2/73)	6	4
Spartina patens	GA(8/73-9/74)	5	8
	DL(9/74-8/75)	5	8
	ME(6,8,9/74;4/75)		
Sporobolus virginicus	GA(10/73-11/74)	5	8

* *Phragmites communis* is a commonly accepted name for the common reed and appears throughout many current literary works, however, the U. S. National Herbarium has recently accepted *P. australis* as the proper name for this grass (Personal Communication, 2 August 1977, Dr. Thomas R. Soderstrom, Agrestologist, Dept. of Botany, Smithsonian Institute, Washington, D. C.).

** 3 cores taken over stems and 3 between stems.

sieve with water. Samples dried at 60°C were ground to pass a 40-mesh sieve and analyzed for carbon content with a Leco WR12 Carbon Determinator. Nitrogen was determined by the Kjeldahl method and P, K, Mg, Ca, Mn, and Fe were assayed by spark emission spectrometry (Jones and Warner, 1969).

Results and Discussion

Macro-organic Matter Profiles

Macro-organic matter profiles in the marshes were of three shapes (Figure 1). In the first type, the concentration was relatively uniform with depth. Macro-organic matter concentration was highest at the surface and decreased with depth in the second type. The third type had a relatively low concentration near the surface, the highest concentration somewhat below the surface, and low concentrations at greater depth. The marsh types exhibiting the three profile types are listed in Table 2.

Biological, physical, and chemical factors influence the shape and MOM concentrations in the profiles. Plant stem growth has both an input and an output role. When stems are initiated from rhizomes, they can increase the underground biomass, assuming some of the input is coming from current photosynthesis and not exclusively from long-term stored material in rhizomes. Work by Hull et al. (1972) indicates the former is likely. Once the young stems break the soil, any translocation to aerial tissue represents an output. Root and rhizome production have only an input role. Type 1 profiles were present

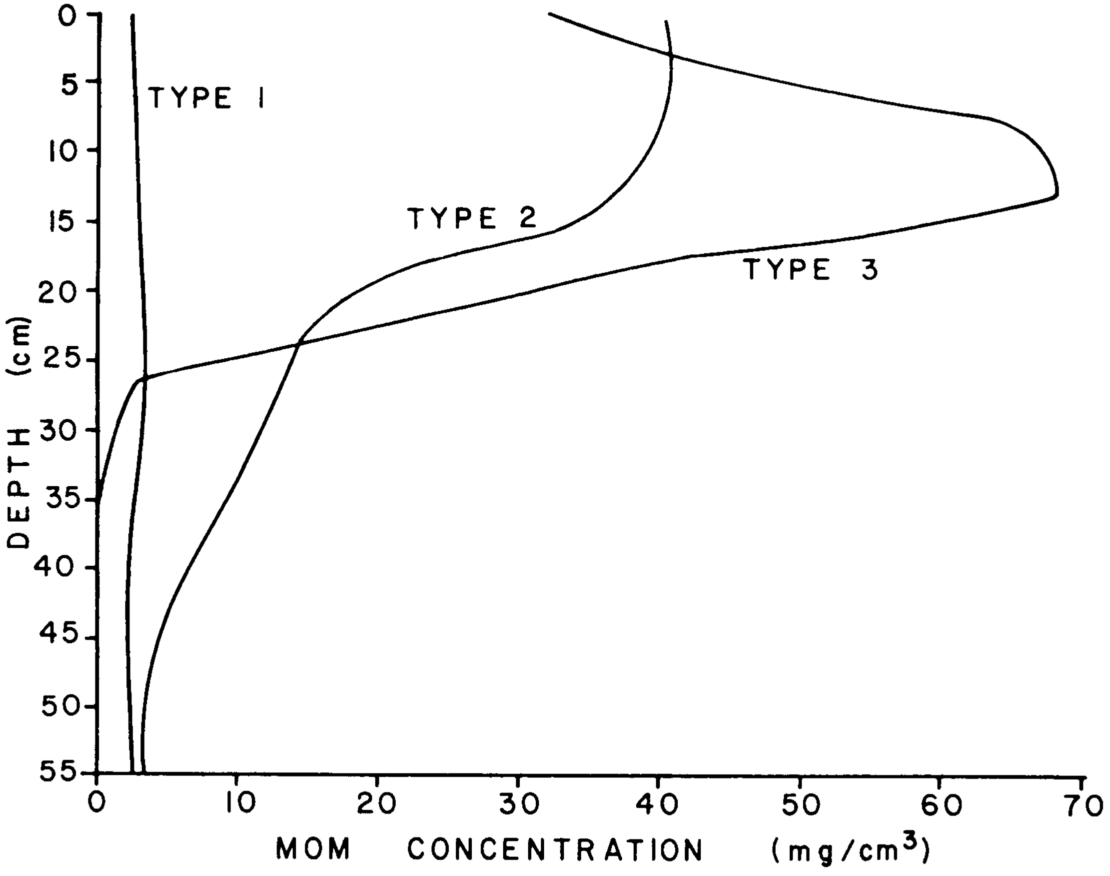

Figure 1

Three Types of Macro-organic Matter Profiles

Table 2

Macro-organic Matter Profile Types Exhibited by Various Marsh Plants at Three Areas of Eastern Coastal Marshes of the United States

Plant	Location*		
	Georgia	Delaware	Maine
Borrichia frutescens	2	-	-
Distichlis spicata	2	3	-
Juncus gerardi	-	2	2
Juncus roemerianus	2	-	-
Phragmites communis	-	3	-
Salicornia virginica	2	2	-
Spartina cynosuroides	2	-	-
Spartina alterniflora			
Creekbank	1	-	3
Creekhead	-	-	1
High marsh	2	-	-
Spartina patens	2	2	2
Sporobolus virginicus	2	-	-

* Numbers correspond to type of profile shown in Figure 1.

where root-shoot ratios were low. In Type 2 profiles, most of the living roots and rhizomes were concentrated within the top 10 cm, whereas in Type 3 profiles, a thick rhizome mat is located 10-20 cm below the surface.

Except in unusual circumstances, the shape of the profiles is dependent primarily on plant species. In Georgia a natural *S. alterniflora* marsh forming on a protected sand beach developed the typical Type 2 profile in 2 years. Although the concentration of MOM was somewhat lower than in older adjacent marshes, the shape of the profile was the same. Similar results were obtained with *S. virginicus* which developed its typical Type 2 profile within 18 months after being planted on 3 types of dredged material in Georgia.

The major departure from a single profile type for a single species was seen with *S. alterniflora*, which grew in a wider range of sites both latitudinally and at various habitats at a single latitude. In Georgia the creekbank *S. alterniflora* has a Type 1 profile while that growing further north has a Type 2. Current evidence is that these differences are environmental rather than genetic. The deeper rooting pattern may be due to better water movement in the creekbank soils (Odum and Riedeburg, 1976). The higher salinity of the soils in the high marsh (35-40‰ compared to 20-28‰ on the creek bank) may restrict the roots to the upper zone where rainfall and tidal water keep the salinities lowest. Haines and Dunn (1976) have reported a reduction in root growth associated with higher salinity media.

When apparent anomalies occur, the historical aspect of the development of the marsh may be important in determining the type of profile found. Fox example, the typical S. virginica stands in Delaware had Type 2 profiles, but one stand was cored which had a Type 1. By examining the MOM and the soil, it was found that the site had been a S. alterniflora marsh on which a thin layer of dredged material had been deposited. This latter substrate was the site for the S. virginica development. The S. virginica root system provided the total input of MOM in the upper 15 cm and the smothered S. alterniflora that for the next 20 cm; these two superimposed Type 2 profiles produced a Type 1 profile.

Although the concentration of macro-organic matter changed during the year, the shape of the profiles did not change significantly in most cases (Figure 2). The major shift was from a Type 2 profile toward a Type 1 as the macro-organic matter in the upper portion of the profile decayed. Since all stands were sampled at 8-week intervals, it was possible to plot an annual cycle for each species. In some stands of marsh plants, clear smooth annual cycles in macro-organic matter were measured (Figure 3) while in others the cycle was less clear (Figure 4). In most stands the culm density was high enough that the cores were large enough to produce means with satisfactory variability. In the stands of S. cynosuroides and Phragmites communis, random samples gave very variable results and collection procedures were modified to remove a pair of cores at randomly selected points. One core was removed from directly over a cut stem base

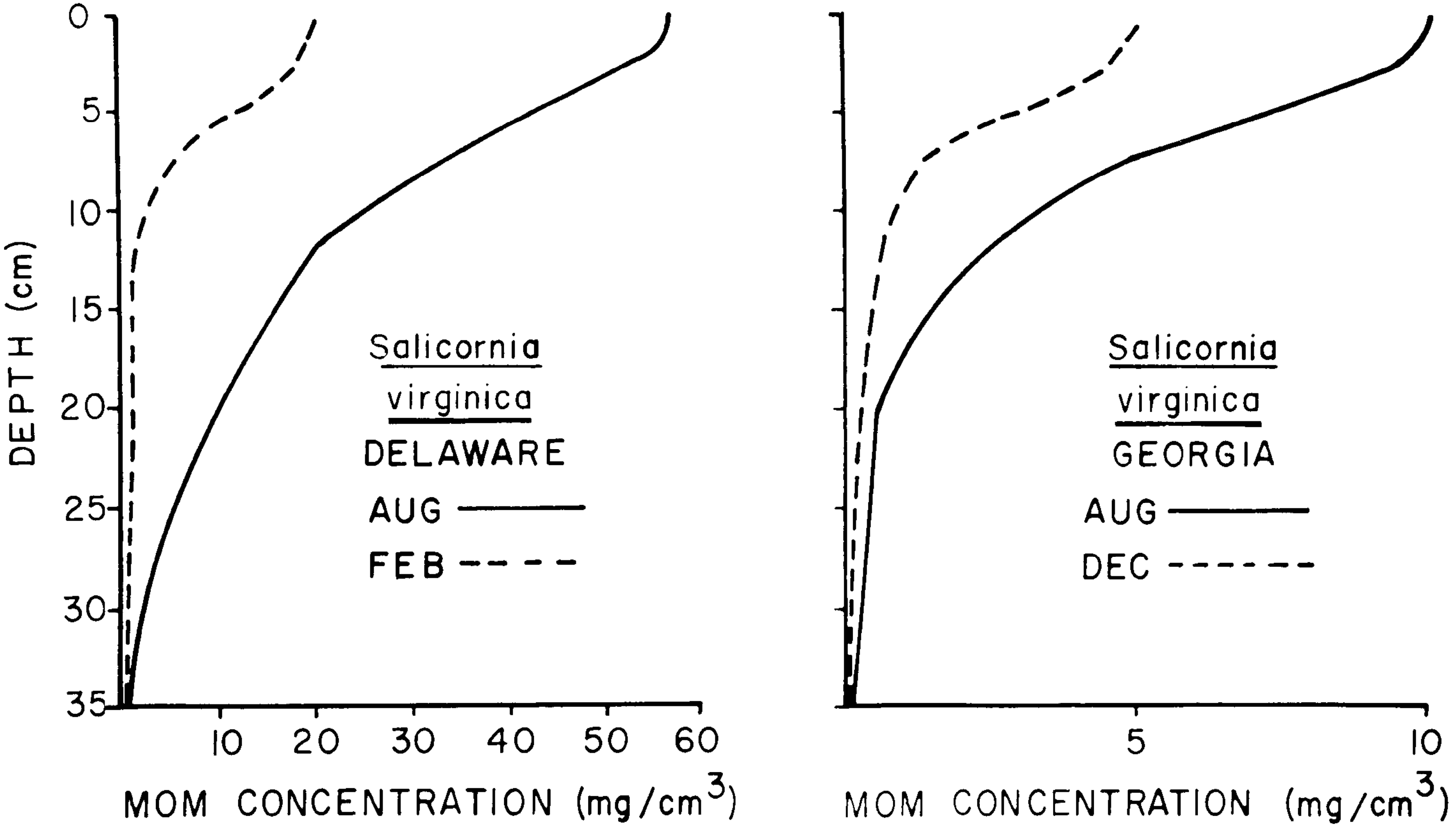

Figure 2

Macro-organic Matter Profiles in _Salicornia virginica_ in Delaware and Georgia

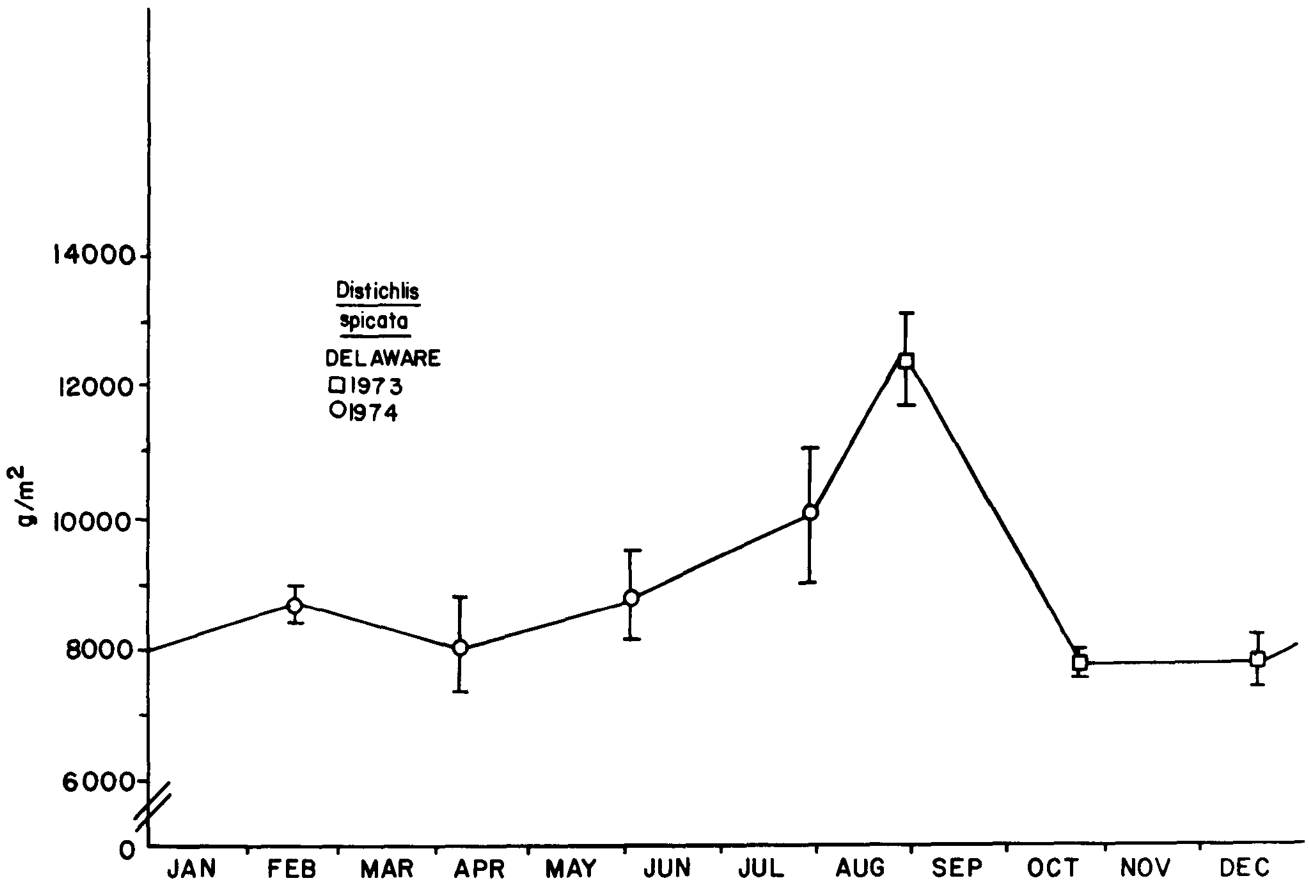

Figure 3

Annual Cycle of Macro-organic Matter to a Depth of 35 cm in a Stand of Distichlis spicata in Delaware.

Bars Represent ± 1 SE

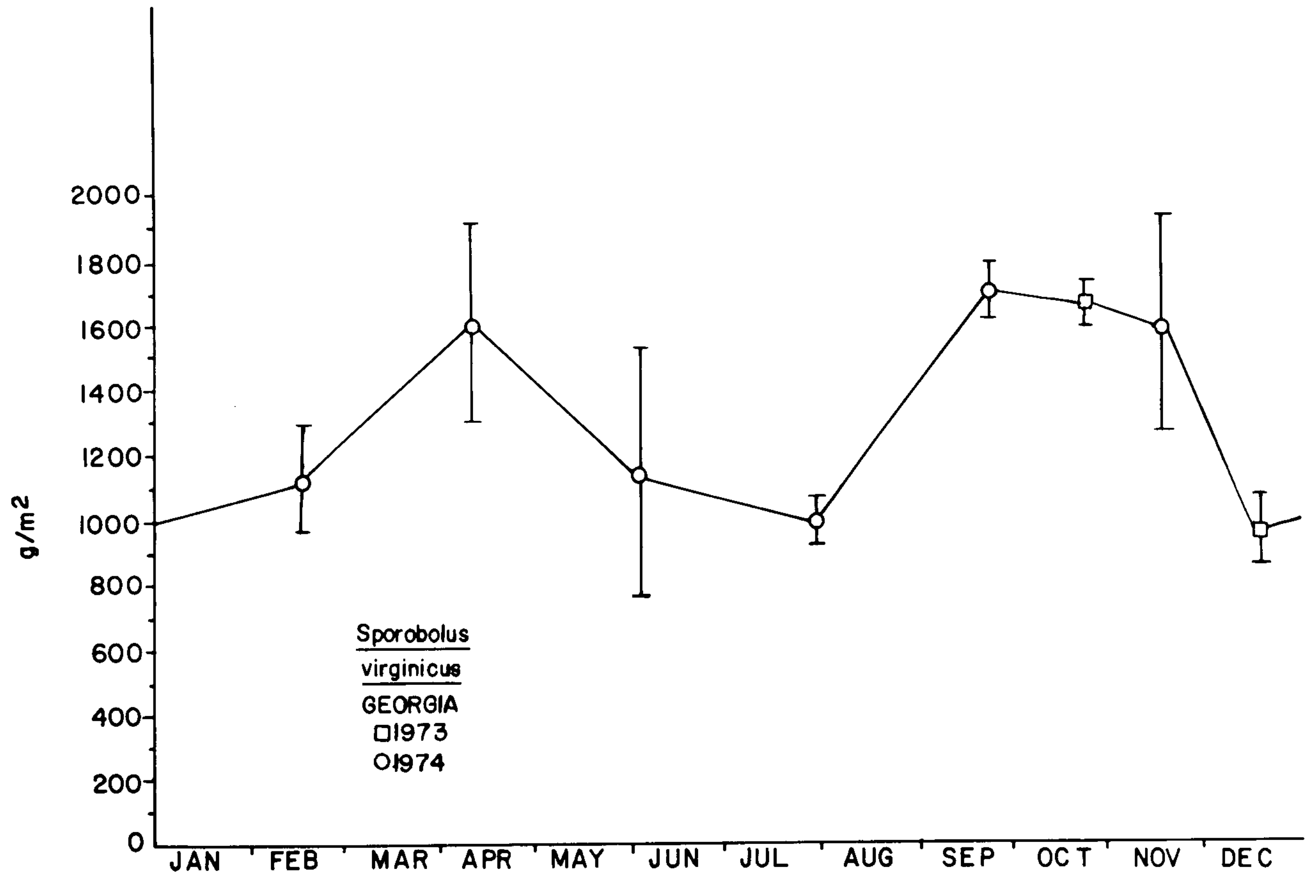

Figure 4

Annual Cycle of Macro-organic Matter to a Depth of 35 cm in a Stand of Sporobolus virginicus in Georgia.

Bars Represent ± 1 SE

while the other member of the pair was taken from between the stem bases. The annual cycle of these two areas within the stand of _S. cynosuroides_ is illustrated in Figure 5. Data for each sampling date for the various plant stands are found in Appendix A.

Annual Increment of Macro-organic Matter

These cycles were used to calculate an annual increment of macro-organic matter for each stand. The maximum was taken as the mean of the several highest readings and the minimum as the mean of the several points from the low part of the cycle. This method had the effect of minimizing the increment. Furthermore, the points used in calculating a mean were not statistically significantly different from one another.

The carbon contents of the underground biomass in the various marsh plant stands are shown in Table 3 and were used to convert the dry weight data to a carbon base. No seasonal differences in carbon content were detected and all measurements were pooled for each stand. The results of the annual increment calculations are summarized in Table 4. These values may be taken as minimum underground production figures. They err on the low side because the underground parts die and decay during the growing season. Total production for the species cannot be obtained by adding the underground production to aerial production since translocation between the underground and aerial parts of the plants will result in the same photosynthate being counted twice. The total minimum production estimate must be based on total maximum and minimum biomass data obtained from a simultaneous aerial and underground sampling program.

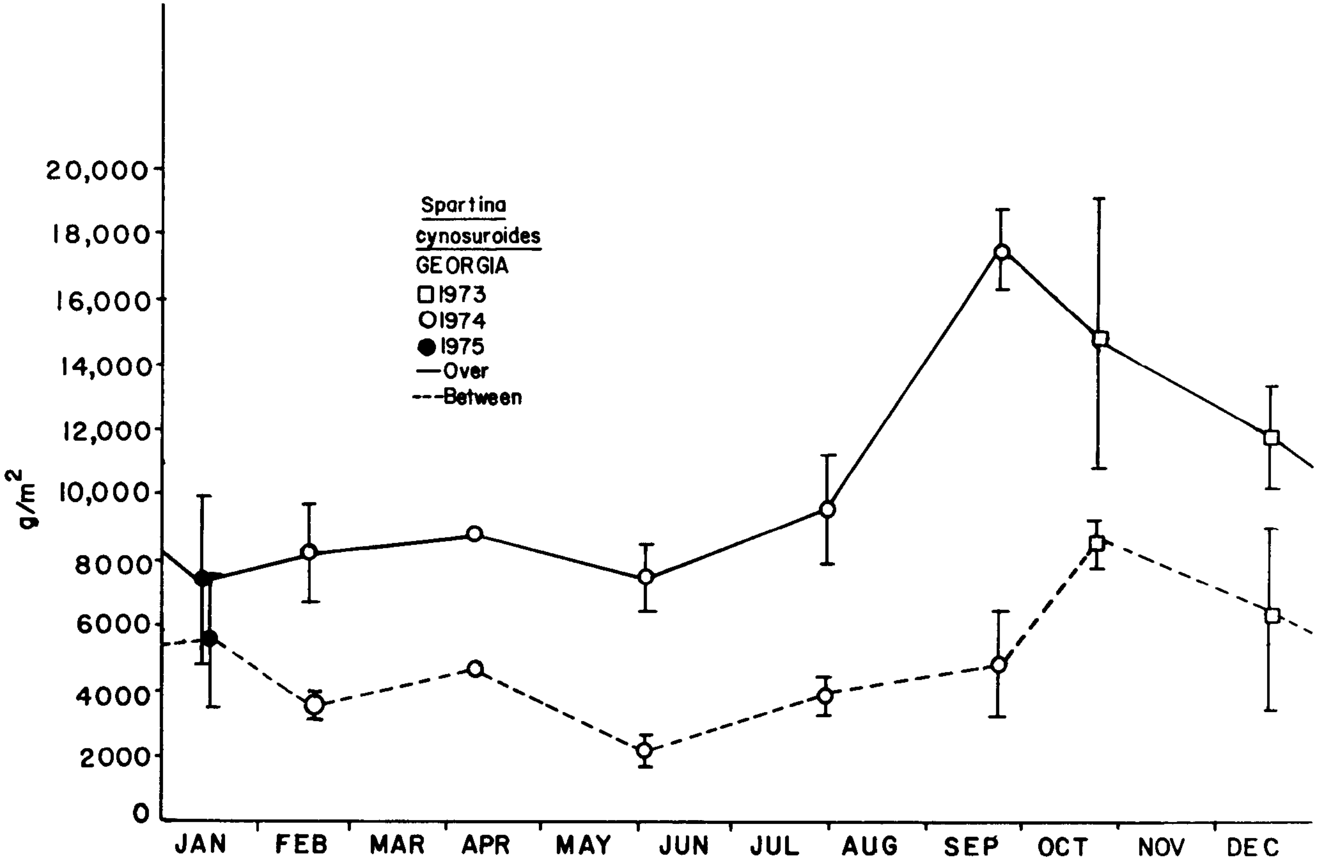

Figure 5

Annual Cycle of Macro-organic Matter to a Depth of 55 cm in a Stand of Spartina cynosuroides in Georgia. Solid Line Represents Cores Taken Over Stems; Broken Line Represents Cores Removed from Between Stems. Bars Represent ± 1 SE

Table 3

Carbon Content ($g\ C/m^2$) of the Underground Biomass in Stands of Salt Marsh Plants

Species	Georgia			Delaware			Maine		
	$\bar{X}$	SE	N	$\bar{X}$	SE	N	$\bar{X}$	SE	N
Borrichia frutescens	39.2	1.4	7		--			--	
Distichlis spicata	39.3	2.5	14	39.7	0.8	43		--	
Juncus gerardi		--		39.4	0.9	29	33.4	1.1	20
Juncus roemerianus	39.9				--			--	
Phragmites communis		--		37.0	1.2	27		--	
Salicornia virginica	32.4	1.0	11	37.0	1.8	16		--	
Spartina cynosuroides	36.5	0.9	25		--			--	
Spartina alterniflora									
Creekbank	36.5				--		36.6	0.7	20
Creekhead		--			--		39.5	3.8	9
High marsh	38.1				--			--	
Spartina patens	38.8	1.2	8	31.8	2.6	12	40.6	0.4	20
Sporobolus virginicus	38.0	2.6	11		--			--	

$\bar{X}$ = arithmetic mean, SE = standard error of the mean, N = number of samples.

Table 4

Annual Increment and Turnover Times of the Underground Macro-organic Matter in Stands of Salt Marsh Plants

Plant	Annual Increment (g C/m^2)			Turnover Time (months)		
	G	D	M	G	D	M
Spartina alterniflora						
Creekbank	771	-	476	18.5	-	118.8
Creekhead	-	-	80	-	-	224.4
High marsh	768	-	-	57.1	-	-
Spartina patens	117	149	220	67.8	91.6	91.6
Spartina cynosuroides	1304	-	-	28.0	-	-
Sporobolus virginicus	221	-	-	33.9	-	-
Distichlis spicata	424	1348	-	40.6	39.5	-
Phragmites communis	-	1338	-	-	27.4	-
Juncus gerardi	-	1686	543	-	22.1	45.6
Juncus roemerianus	1338	-	-	44.0	-	-
Salicornia virginica	142	528	-	26.4	24.5	-
Borrichia frutescens	321	-	-	18.4	-	-

G = Georgia, D = Delaware, M = Maine.

The time to turn over the total macro-organic matter pool in the soil was calculated by dividing the increment into the maximum biomass. This total pool is no doubt composed of several sub-pools with different turnover times, with the most rapid turnover in a matter of days and the most refractory taking centuries.

In Georgia stands of S. alterniflora, the creekbank and high marsh had equal annual increments but the turnover time was much more rapid in the creekbank area due to the threefold greater quantity of MOM in the high marsh. In comparing the Georgia creekbank with a similar site in Maine, the increment was found to be about 60% of the Georgia stand while the turnover time was 6 times longer in the cooler area. On the other hand, the annual increment of S. patens increased with latitude. This might be expected since S. patens is a much more important component of the marsh flora at the higher latitudes. Similarly, D. spicata, whose annual increment increased with latitude, is more prevalent in the Delaware marsh than in Georgia.

These data indicate that the dynamics of the underground macro-organic matter is as great or often greater than the aerial dynamics. The factors regulating the translocation of photosynthate to the underground pool and the dispersion of this stored carbon either back to the aerial parts of the plant or to the soil detritus food web are of immense consequence to the salt marsh ecosystem and are now the subject of this research.

Mineral Composition

The mineral composition of the underground macro-organic matter was typified by the D. spicata data shown in Table 5. Data on the mineral composition of other species are found in Appendix B. Nitrogen, phosphorus, and potassium all decreased with depth. The deeper samples appeared to contain more dead material and hence would be expected to have lower quantities of the macronutrients. Nitrogen, for example, will likely be conserved and removed from the dying tissue. Since the potassium is not bound to compounds in the plants but exists as a free ion, it will leach quickly when the integrity of the membranes is lost as the cells senesce. No particular pattern was seen for Ca, Mg, Mn, or C; but a pattern similar to that for N, P, and K was observed for Zn.

When the quantity of N bound in the MOM was compared along the latitudinal gradient using June harvest data, the highest quantity was found at the most northerly sites in 4 of the 5 cases studied (Table 6). In all cases the C:N ratio decreased with increasing latitude. The mean areal nitrogen content for the underground MOM for all the species studied was 65.4 g N/m^2 with a coefficient of variation of 70. The mean C:N ratio for the same species was 35.5 with a coefficient of variation of only 19. Thus the relative amount of N to the C present is more consistent from one plant stand to another than is the absolute amount of N.

Table 5

Mineral Composition of Underground Macro-organic Matter in a Stand of *Distichlis spicata* in Delaware in February, June, and November

Month	Depth cm	Percent N	Percent P	Percent K	Percent Ca	Percent Mg	PPM Mn	PPM Cu	PPM Zn
February	0-5	1.39(.04)*	.13(.02)	.35(.09)	.31(.14)	.26(.04)	20(10)	17(7)	179(33)
	5-10	1.18(.09)	.08(.03)	.34(.09)	.26(.03)	.32(.02)	20(4)	20(9)	140(122)
	10-15	1.00(.16)	.03(.03)	.19(.10)	.21(.03)	.28(.07)	9(4)	16(9)	36(16)
	15-35	.98(.04)	.01(.01)	.08(.14)	.22(.08)	.22(.05)	20(4)	5(4)	45(32)
June	0-5	1.33(.11)	.15(.07)	.33(.05)	.20(.04)	.25(.06)	31(7)	13(4)	159(66)
	5-10	1.35(.11)	.10(.04)	.25(.05)	.24(.04)	.32(.03)	32(3)	22(4)	64(14)
	10-15	1.39(.10)	.08(.03)	.20(.03)	.34(.05)	.33(.03)	29(2)	20(2)	40(14)
	15-35	.91(.14)	.02(.02)	.08(.03)	.24(.10)	.19(.08)	14(8)	6(2)	39(14)
November	0-5	1.45(.07)	.12(.06)	.34(.17)	.43(.13)	.34(.08)	25(9)	17(9)	84(15)
	5-10	1.27(.04)	.06(.03)	.25(.13)	.35(.03)	.39(.03)	16(5)	21(11)	26(12)
	10-15	1.00(.24)	.07(.02)	.27(.10)	.36(.04)	.26(.04)	18(2)	18(6)	22(6)
	15-35	.75(.06)	.08(.04)	.15(.14)	.31(.10)	.23(.06)	27(16)	11(7)	24(13)

* Numbers in parentheses are standard errors.

Table 6

Grams N/m^2 to a Depth of 35 cm and C:N Ratios of Underground Macro-organic Matter from Stands of Marsh Plants

Plant	Location	$g\ N/m^2$	C:N
Borrichia frutescens	GA	12	39
Distichlis spicata	GA	44	33
	DL	156	28
Juncus gerardi	DL	94	33
	ME	68	30
Juncus roemerianus	GA	123	40
Phragmites communis	DL	83	37
Salicornia virginica	GA	12	27
	DL	41	26
Spartina cynosuroides	GA	70	41
Spartina alterniflora	GA*	98	38
	ME†	129	32
Spartina patens	GA	14	48
	DL	27	45
	ME	61	29
Sporobolus virginicus	GA	15	42

* High marsh.
† Creekbank.

PART III: COMPARISON OF SOME TIDAL MARSH SOILS ALONG THE ATLANTIC COAST

Introduction

Interest in salt marsh soils has increased since the value of marshes as natural resources and as their potential for development has been realized. Concern has developed about how to restore damaged marshes or create new marsh areas to replace those destroyed by development and pollution. The U. S. Army Corps of Engineers has taken the initiative in creating marshes on dredged material. A knowledge of the properties of marsh soils is necessary for two reasons. First, the description of marsh soils is useful in order to predict the soil requirements for various plants. Second, the information enables the scientist to tell how far a newly established marsh has progressed toward the conditions of a natural marsh.

The soil descriptions included in this report cover a wide range of situations from Maine to Georgia. They were selected because they were believed to bracket all of the types which might be encountered along the east coast of the United States.

Methods

The approach in this study was to make field descriptions on the sites by either working from the faces of large walk-in pits or with shovel samples removed from small (0.5 m^2) pits. The former technique was used in the better drained and firmer substrates while the latter was used in areas where the water table was near the surface or the substrate was not firm enough to support the wall.

Bulk density was obtained using a series of short cores so that compaction would not be a problem (Gallagher, 1974). In situ pH was obtained by placing the probe directly in the moist soil.

Soil samples were removed from each of the horizons and returned to the laboratory where they were freeze-dried and ground in a Wiley mill until they passed a 40-mesh sieve. In addition to the soils collected at the study sites, three types of dredged material were collected and analyzed in the same way as the soils. All materials were collected from near the low tide elevation and are thus more characteristic of the fresh dredged material than that piled high in the intertidal zone. All samples were taken from dredged material placed at the site less than 90 days earlier. The silt and clay material was collected from a site 300 meters north of the drawbridge leading to Jekyll Island on the western side of the Inland Waterway. The sand substrate was collected from the eastern side of Buttermilk Sound on the site which was subsequently to be a marsh-creation site developed by the Dredged Material Research Program (DMRP). The third was a sand and clay mixture collected from the north side of the Darien River where it intersects with May Hall Creek.

Salinity characteristics were measured by putting 100 grams of soil on No. 54 Whatman filter paper in a funnel and leaching it with successive 50-ml volumes of distilled water. Each leachate salinity was measured and the leachate saved. When the salinity of the last leachate increment was zero, the total amount of water was called the leaching volume. The soil salinity was calculated from the salinity of the leachate and the volume of the water collected. The leaching volume was divided by soil salinity to give an index (desalination index) of the ease of removing the salt from the soil.

The pH of the dried and oxidized soil was measured first in a 1:1 water:soil mixture (pH^W) and then after treatment with buffer solution (pH^B) as described by Adams and Evans (1962). Total N content was determined by Kjeldahl digestion (Bremner, 1965). A double acid extraction of a soil sample was performed using HCl and H_2SO_4 according to the methods described by Nelson et al. (1953). The extract was analyzed for P, K, Ca, and Mg according to the methods described by Isaac and Jones (1970). Sodium, iron, and manganese were assayed by atomic absorption spectroscopy (Isaac and Kerber, 1971). Ammonium and nitrate nitrogen were measured by the methods described by Bremner and Keeney (1966) and chloride by potentiometric titration (Lacroix et al., 1970).

Results and Discussion

Soil Profiles and Structure

The profile descriptions for soils from Georgia, Delaware, and Maine are shown in Appendix C. Colors were primarily blacks, grays, and greens reflecting the waterlogged reduced nature of these soils. In Georgia and Delaware the soils higher in the intertidal zone tended toward lighter texture. Since these soils are inundated less frequently by silt and clay-laden tidal water, deposition of finer grade sediments was less. The coarse-grained sediments were loose with little evidence of ped formation.

Similarly, the fine-grained sediments were massive and little structural development occurred presumably because of the effects of the high sodium content of the soil. In the J. gerardi stand in Delaware, subangular blocky peds were found.

Bulk density profiles for soils from the three states are shown in Figures 6, 7, 8. The Georgia profiles were generally more uniform with depth than were those from the other two states. Two groups could be distinguished from the Georgia set. Salicornia virginica, S. patens, and S. virginicus which developed on sandy substrate formed one group, while B. frutescens, D. spicata, and S. cynosuroides which developed on substrates composed primarily of silt and clay formed a second.

The much lower bulk densities generally measured at the surface in Delaware and Maine reflect the greater peat development at these locations. Slower decay rates and lower silt loads in the water are probably the major factors responsible for these differences.

The in situ reaction of the soils varied from 8.8 in soil horizon All in D. spicata in Georgia to 5.0 in soil horizon A22g in J. gerardi in Maine (Appendix C).

The higher values are typical of those found in seawater. Most of the values were close to pH 7.0 and much of the variation around that point may reflect the effects of the wetness of the soil on the Na^+, H_3O^+ balance in the soil (Table 7). As the moisture increases the H_3O^+ becomes more abundant relative to the Na^+ and more H_3O^+ is associated with the cation exchange capacity (C.E.C.) sites in the soil. This condition leaves relatively more OH^- in solution and the pH rises. In the cases where the pH was found to be low, organic acids resulting from anaerobic

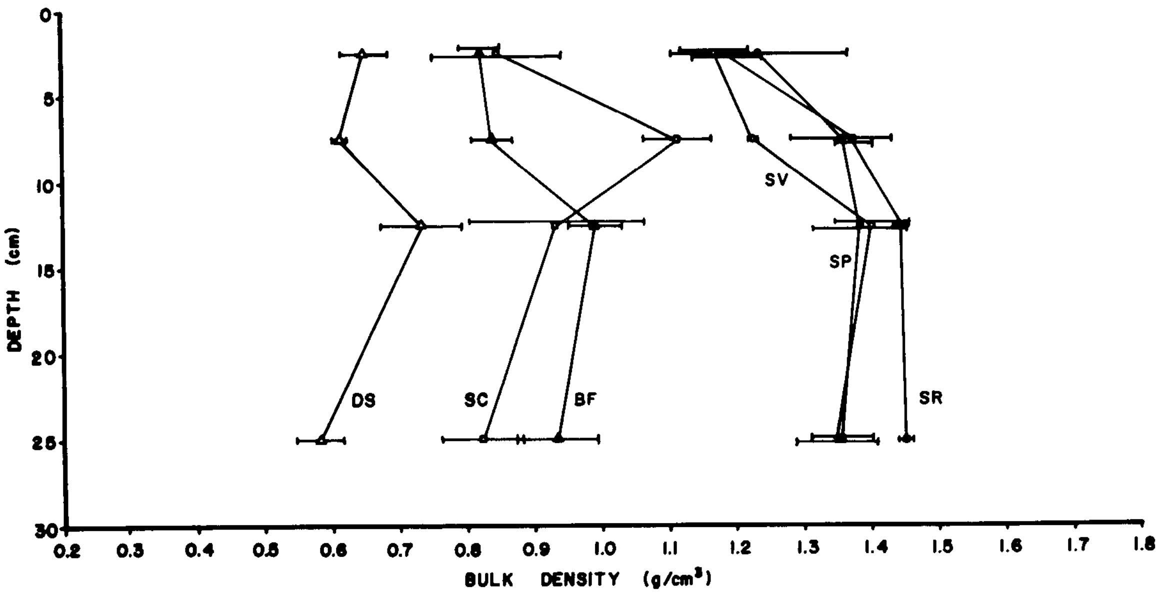

Figure 6

Bulk Density (g/cm^3) Profiles from Marsh Soils in Georgia.

BF-<u>Borrichia frutescens</u>, DS-<u>Distichlis spicata</u>,

SC-<u>Spartina cynosuroides</u>, SP-<u>Spartina patens</u>,

SR-<u>Sporobolus virginicus</u>, SV-<u>Salicornia virginica</u>

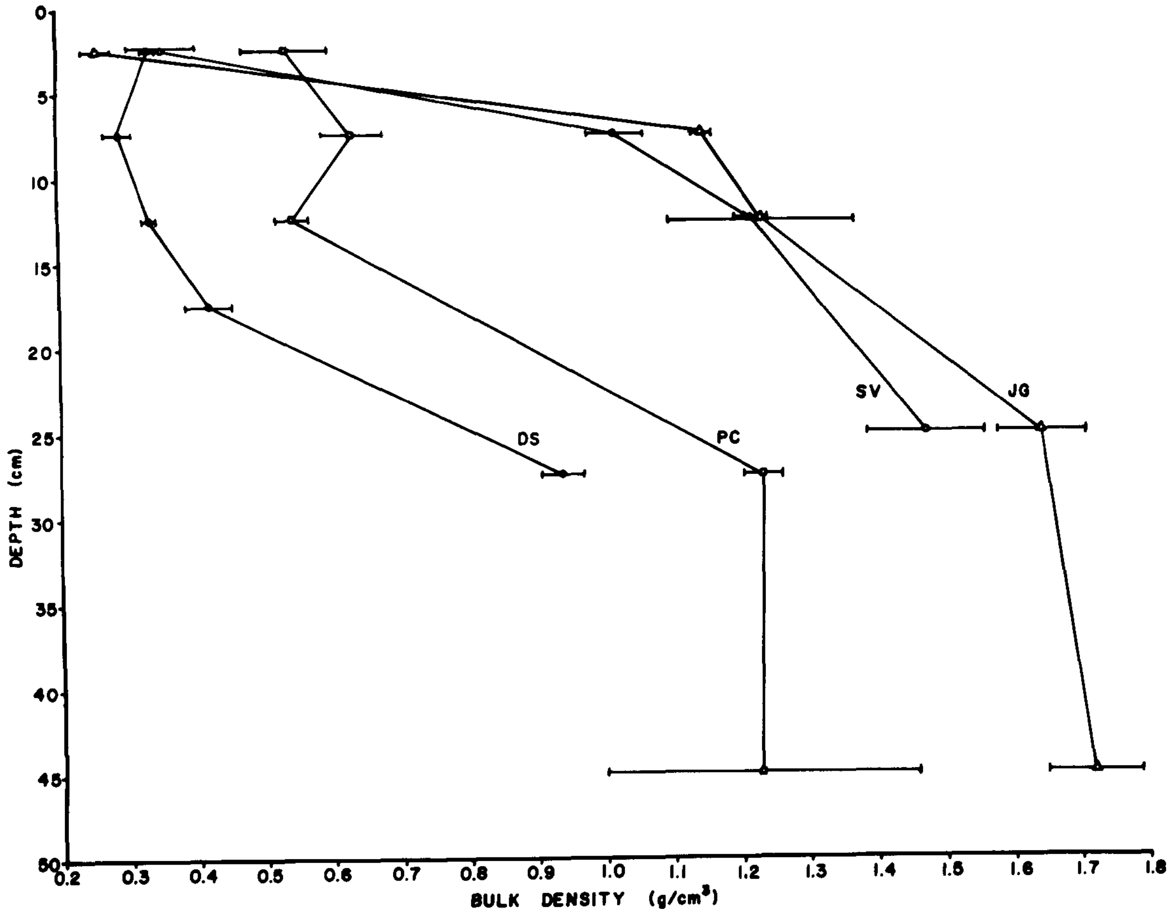

Figure 7

Bulk Density (g/cm^3) Profiles from Marsh Soils in Delaware.

DS-*Distichlis spicata*, JG-*Juncus gerardi*,

PC-*Phragmites communis*, SV-*Salicornia virginica*

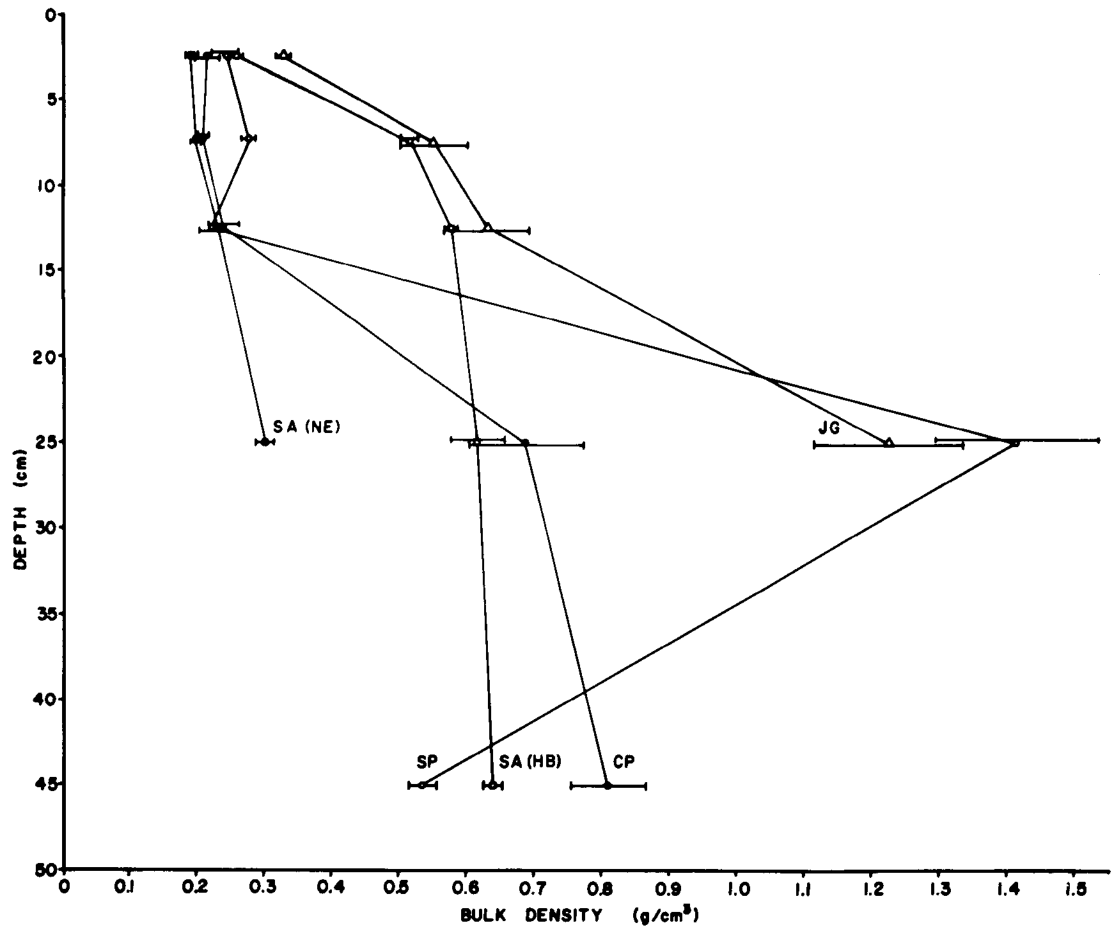

Figure 8

Bulk Density (g/cm^3) Profiles from Marsh Soils in Maine. CP-*Carex paleacea*, JG-*Juncus gerardi*, SA(HB)-*Spartina alterniflora*-Hoy Bay marsh, SA(NE)-*Spartina alterniflora*-North East marsh, SP-*Spartina patens*

Table 7

Effect of Soil-Water Ratio on the pH of *Spartina alterniflora* Marsh Soils

Parts Soils	Parts Water	pH
2	0	6.90
2	1	7.05
2	2	7.18
1	2	7.34
0	2	6.00

decay may be responsible for the acidic condition. In none of the cases where the pH was low did the soils appear well enough aerated to have oxidized sulfides and thus exhibit the cat-clay phenomenon.

Salinity

The salinity characteristic of the soil (Table 8) is one of the important properties determining which plants can thrive, or, in fact, survive. The first characteristic which was measured was the salt concentration. These data indicate the salinity characteristic of the soil on which the various marsh plants grow. These numbers do not, however, reflect the salinity to which the plants are exposed since the moisture content of the soil will cause the interstitial water salinity to vary widely. Gallagher and Daiber (1974) reported interstitial water salinities in a salt pan ranged from 34‰ in the spring to 89‰ in the summer Although the salinity on a dry weight basis does not indicate the condition under which the plants might be growing at any given time, it is a relatively conservative property which, when coupled with the moisture content, will indicate the stress under which the plant will be placed. The three types of dredged material from Georgia were widely different in salinity, and hence the kinds of plants they might support would depend on the moisture regime under which they might be placed and the degree to which they were leached by rainfall or low salinity tidal water. In order to determine how readily the salt could be removed, the soil was leached with increments of fresh water until no more salts could be removed. This leaching volume was divided by the salinity to give a desalination index. The higher the

Table 8

Salinity Characteristics of Soil Horizons from Several Stands of Marsh Plants

Species	Depth (cm)	Salt Concentration (‰)	Salt Leaching Volume (ml) (LV)	Salt Desalination Index (DI)
GEORGIA				
Borrichia frutescens	0-4	17	720	42
	4-28	8	720	90
	28-64	11	480	44
	64-125	12	240	20
Distichlis spicata	0-37	32	1200	38
	37-100	18	880	49
	100-135+	13	560	43
Salicornia virginica	0-7	16	320	20
	7-32	21	240	11
	32-80	19	240	13
	80-125	19	880	46
Spartina cynosuroides	5-20	6	240	40
	20-52	4	160	40
	52-85	6	480	80
Spartina patens	0-25	12	160	13
	25-47	8	240	30
	47-130	8	240	30
	130+	6	240	40
Sporobolus virginicus	0-3	7	160	23
	3-13	9	240	27
	13-34	7	160	23
	34-150+	6	160	27
Dredged material	silt & clay	148	2320	16
	sand	1	20	20
	sand & clay	9	160	18

(Continued)

LV = volume (ml) of fresh water necessary to remove leachable salts from 100 grams of soil

DI = leaching volume (LV)/soil salinity (‰).

Table 8 (Continued)

Species	Depth (cm)	Salt Concentration (‰)	Salt Leaching Volume (ml) (LV)	Salt Desalination Index (DI)
DELAWARE				
Distichlis spicata	19-29	11	480	44
	29-45	9	400	44
Juncus gerardi	0-20	5	400	80
	20-30	8	320	40
	30-50	6	240	40
	50-80	4	160	40
Phragmites communis	0-25	0	0	
	25-75	2	160	80
	75+	4	240	60
Salicornia virginica	0-8	13	560	43
	8-53	6	240	40
	53-70	6	240	40
Spartina patens	15-35	22	1120	51
	35-65	20	960	48
	65-100+	5	560	112
MAINE				
Carex paleacea	0-23	46	2240	49
	23-46	21	960	46
	46-71	14	640	46
	71-97	9	880	98
Juncus gerardi	0-3	20	960	48
	3-8	16	720	45
	15-25	3	240	80
	25-30	8	320	40
	30-43	3	240	80
	43-89	4	320	80
	89-114	4	320	80

(Continued)

Table 8 (Concluded)

Species	Depth (cm)	Salt Concentration (‰)	Leaching Volume (ml) (LV)	Desalination Index (DI)
MAINE, continued				
<u>Spartina</u> <u>alterniflora</u> creekbank	0-13	67	2080	31
	13-28	39	1120	29
	28-41	11	480	44
	41-91	0	0	0
<u>Spartina</u> <u>alterniflora</u> high marsh	15-25	14	640	46
	25-61	16	800	50
	61-94	18	800	44
<u>Spartina</u> <u>patens</u>	0-8	57	2720	48
	8-15	61	1920	31
	15-28	40	2320	48
	28-61	25	1040	42
	61-102	25	1200	48

index the more difficult the salt was to remove. In the case of the three types of dredged material, although the salinity was greatly different and leaching volume (LV) varied by 2 orders of magnitude, the ease with which each unit of salinity was removed was similar. In contrast, in the _B. frutescens_ the desalination index (DI) for the 4-28 cm horizon was 4.5 times that for the 64-125 cm zone.

pH

The pH characteristics (Tables 9, 10, 11) of the freeze-dried soils are expressed as pH^W for the samples mixed with water and pH^B for those measured in buffer. When these are combined with pH in situ, the reaction of the material being exposed to oxidation can be assessed. The drop in pH from the in situ reading to the pH^W measurement indicates what would be expected if the substrate were placed higher in the intertidal zone as the result of dredging or if the soils were drained. While the pH^W gives an indication of the intensity of the acidity, pH^B is an indicator of the quantity of hydronium ions present. In Table 9, for example, the pH of the 64-125 cm horizon in _B. frutescens_ has a pH^W of 4.1 indicating a low pH probably caused by oxidation of sulfides. The pH^B is 7.5, only half a unit below the original buffer pH of 8.0 indicating the acid buffering capacity is not great. This contrasts with the situation in the 0-37 cm horizon of _D. spicata_ (Table 9) where the pH^W was 5.0 and the pH^B dropped to 6.4 indicating a high lime requirement to neutralize the oxidation effects.

Table 9

Chemical Properties of Tidal Marsh Soil Along the Atlantic Coast (Georgia)*

Depth cm	pH^W	pH^B	P	K	Ca	Mg	Na	Fe	Mn	Cl	NO_3	Total N	Total C	NH_4
Borrichia frutescens														
0-4	7.2	7.7	48	563	3240	1130	1600	10	33	96,400	13.0	0.27	1.97	21.0
4-28	6.6	7.8	114	558	3300	1120	1450	14	20	56,700	24.0	0.22	1.22	56.0
28-64	6.5	7.7	230	350	3000	700	1350	28	12	51,000	27.0	0.18	0.58	27.0
64-125	4.1	7.5	370	220	2580	490	1050	52	1	22,700	7.0	0.08	0.40	13.0
Distichlis spicata														
0-37	5.0	6.4	6	188	1620	630	1430	8	3	164,500	66.0	1.06	14.31	8.0
37-100	5.0	6.6	9	275	2820	1100	1440	2	1	56,700	25.0	0.43	5.59	27.0
100-135	5.1	7.8	20	200	1860	655	1100	3	1	48,200	7.0	0.15	2.80	33.6
Salicornia virginica														
0-7	7.3	7.8	6	300	2760	970	1670	44	3	53,800	15.4	0.07	0.31	63.0
7-32	7.3	7.9	2	250	2520	810	1840	14	4	144,600	22.0	0.07	0.14	87.0
32-80	7.6	7.9	4	250	2580	810	1590	10	1	31,900	6.0	0.15	0.10	61.0
80-125	6.0	7.7	19	608	3300	1120	2370	37	1	195,600	3.0	0.08	0.55	1.0

(Continued)

* Total N and C are in % while all other ions are in PPM.

Table 9 (Concluded)

Depth cm	pH^W	pH^B	P	K	Ca	Mg	Na	Fe	Mn	Cl	NO_3	Total N	Total C	NH_4
Spartina cynosuroides														
5-20	6.3	7.8	120	238	2520	590	540	28	34	25,500	11.0	0.10	0.96	1.0
20-52	7.0	7.8	210	153	2280	380	360	48	19	14,200	8.4	0.10	0.62	25.2
52-85	6.2	7.6	32	265	1800	430	510	165	11	31,200	15.4	0.21	2.29	49.0
Spartina patens														
0-25	6.3	7.8	120	213	1920	525	1140	27	2	14,200	4.0	0.11	0.65	1.0
25-47	5.9	7.8	20	150	1500	470	1060	6	1	36,900	13.0	0.12	0.30	64.0
47-130	5.9	7.4	126	205	1740	630	850	2	1	11,300	19.6	0.12	1.30	94.0
130-160	5.7	7.6	160	263	1320	490	870	9	1	48,200	24.0	0.09	0.30	14.0
Sporobolus virginicus														
0-3	6.9	8.0	6	163	1440	460	860	9	1	5,700	7.0	0.10	0.34	13.0
3-13	6.7	7.8	3	180	1680	540	1150	10	1	62,400	7.0	0.08	0.81	11.0
13-35	6.6	7.9	2	113	912	350	910	4	1	59,600	15.0	0.05	0.24	66.0
35-150	5.8	7.4	58	213	1680	640	880	9	3	64,000	3.0	0.11	1.23	10.0

Table 10

Chemical Properties of Tidal Marsh Soil Along the Atlantic Coast (Delaware)*

Depth cm	pH^W	pH^B	P	K	Ca	Mg	Na	Fe	Mn	Cl	NO_3	Total N	Total C	NH_4
Distichlis spicata														
0-19	5.7	7.6	34	663	3840	1360	2410	66	2	I.A.	13.0	0.67	I.A.	67.0
19-29	6.6	7.8	42	338	1680	350	960	205	2	161,700	3.0	0.10	0.90	45.0
29-45	6.8	7.8	30	270	1620	360	880	81	2	11,300	14.0	0.07	0.52	7.0
45-75	6.7	7.8	5	203	1320	350	850	63	2	62,400	29.0	0.09	I.A.	4.0
Juncus gerardi														
0-20	6.0	7.7	6	220	1440	420	610	55	10	19,900	15.4	0.20	1.33	37.8
20-30	5.7	7.6	8	225	1380	440	680	46	3	11,300	7.0	0.11	1.36	22.4
30-50	5.9	7.7	10	175	1080	350	570	15	1	19,900	15.4	0.09	0.80	11.2
50-80	6.3	7.8	2	128	720	215	450	9	1	11,300	4.2	0.12	0.26	63.0
Salicornia virginica														
0-8	6.3	7.8	18	365	2640	870	1660	52	3	53,800	12.6	0.13	1.01	67.2
8-53	5.4	7.8	6	135	1500	460	950	16	1	36,900	7.0	0.06	0.29	16.8
53-70	5.5	7.8	6	138	1440	510	900	14	1	19,900	5.6	0.07	0.25	30.9
70+	6.3	7.8	4	150	840	300	700	35	4	8,600	8.0	0.09	I.A.	29.0

(Continued)

* Total N and C are in % while all other ions are in PPM.
I.A. - Insufficient amount obtained for analysis.

Table 10 (Concluded)

Depth cm	pH^W	pH^B	P	K	Ca	Mg	Na	Fe	Mn	Cl	NO_3	Total N	Total C	NH_4
Spartina patens														
0-15	5.8	7.5	11	625	4080	1480	2840	35	4	70,900	11.0	1.08	I.A.	132.0
15-35	6.6	7.6	28	350	2400	1250	1680	26	1	209,900	1.4	0.39	4.51	65.8
35-65	6.3	7.6	18	290	3000	1380	2040	18	1	51,000	23.8	0.33	4.99	63.0
65-100	4.3	7.6	4	125	1440	490	980	38	1	31,200	15.4	0.10	0.69	32.2
Phragmites communis														
0-25	6.8	7.6	12	415	1080	640	350	47	8	31,200	7.0	0.43	4.92	43.4
25-75	5.8	7.8	22	75	480	170	270	28	3	14,100	10.2	0.06	I.A.	44.8

Table 11

Chemical Properties of Tidal Marsh Soil Along the Atlantic Coast (Maine)*

Depth cm	pH^W	pH^B	P	K	Ca	Mg	Na	Fe	Mn	Cl	NO_3	Total N	Total C	NH_4
Carex paleacea														
0-9	5.9	7.2	20	575	2760	950	1920	53	2	53,800	7.0	0.69	11.51	115.0
9-18	3.3	6.6	48	38	1320	570	610	55	2	62,400	8.0	0.30	3.68	14.0
18-28	5.0	6.7	55	115	1080	470	500	63	3	42,500	4.0	0.31	4.21	32.0
28-38	5.0	7.2	67	158	1500	700	510	59	3	82,200	10.0	0.28	3.53	83.0
Juncus gerardi														
0-1	6.6	7.6	30	525	2760	1200	1100	42	7	34,000	11.2	0.52	5.80	246.4
1-3	6.3	7.0	20	450	2700	730	1130	39	3	110,600	12.6	0.40	4.22	138.6
3-6	5.4	7.4	34	388	3060	1100	1600	27	1	90,800	22.0	0.39	4.51	244.0
6-10	5.4	7.5	12	313	1920	765	1000	48	1	56,700	1.4	0.20	2.57	79.8
10-12	5.2	7.6	10	203	1200	430	740	42	1	42,500	I.A.	0.05	1.82	I.A.
12-17	5.3	7.6	8	200	660	230	400	37	1	8,500	15.4	0.10	0.60	86.8
17-35	4.5	7.4	8	325	1020	400	590	49	1	122,000	15.4	0.13	0.27	44.8
35-45	6.2	7.6	140	188	1560	470	650	32	2	28,400	8.4	0.12	0.16	5.6
Spartina alterniflora (Hoy Bay)														
6-10	4.3	7.3	37	665	2400	630	980	72	2	19,900	11.2	0.36	2.32	67.2
10-24	5.2	7.6	95	565	2520	890	1030	48	1	5,700	8.4	0.34	2.82	161.0
24-37	4.8	7.4	94	565	2280	750	1040	52	2	65,200	14.0	0.34	2.12	152.6

(Continued)

* Total N and C are in % while all other ions are in PPM.
I.A. - Insufficient amount obtained for analysis.

Table 11 (Concluded)

Depth cm	pH^W	pH^B	P	K	Ca	Mg	Na	Fe	Mn	Cl	NO_3	Total N	Total C	NH_4
Spartina alterniflora (Northeast Creek)														
0-5	6.6	7.7	36	965	4380	1700	1710	32	1	8,500	15.4	0.80	I.A.	225.4
5-11	6.3	7.8	18	365	2640	870	1660	52	3	53,800	12.6	0.13	4.61	67.2
11-16	3.7	7.1	45	233	2040	700	1180	71	8	62,400	1.4	0.18	2.62	42.0
16-36	7.0	7.7	150	188	1560	490	650	34	9	28,400	25.2	0.10	0.15	120.4
Spartina patens														
0-3	5.9	7.5	41	888	4200	1680	2520	32	1	250,900	57.0	0.72	8.19	148.0
3-6	3.6	6.8	38	938	4740	950	3620	34	2	25,500	3.0	0.90	I.A.	112.0
6-11	4.3	7.0	32	675	3960	1500	2790	53	1	99,300	14.0	0.70	7.39	6.0
11-24	3.5	6.8	59	300	1740	710	1230	56	2	25,500	24.0	0.39	3.64	22.0
24-80	3.8	7.0	58	363	1980	740	1150	62	3	119,100	85.0	0.38	2.79	17.0

Chemical Properties

Extractable Ca was higher than Mg. This is similar to the situation found by Coultas and Calhoun (1976) in soils in north Florida. Extractable NH_4 was almost always several times to an order of magnitude more abundant than NO_3 refelcting the generally reduced conditions in these soils. The trend toward more extractable NH_4 with increasing latitude was particularly evident when the Maine soils were compared to those in Delaware. In contract, NO_3^- values were approximately the same at all latitudes. Generally, total nitrogen decreased with depth, but this trend was not evident in several of the Georgia soils. The correlation between total carbon and total nitrogen was high ($r = 0.94$) as shown in Figure 9. The slope was significantly different from 0 and the line can be described by the equation $Y = 13.16X = 0.64$.

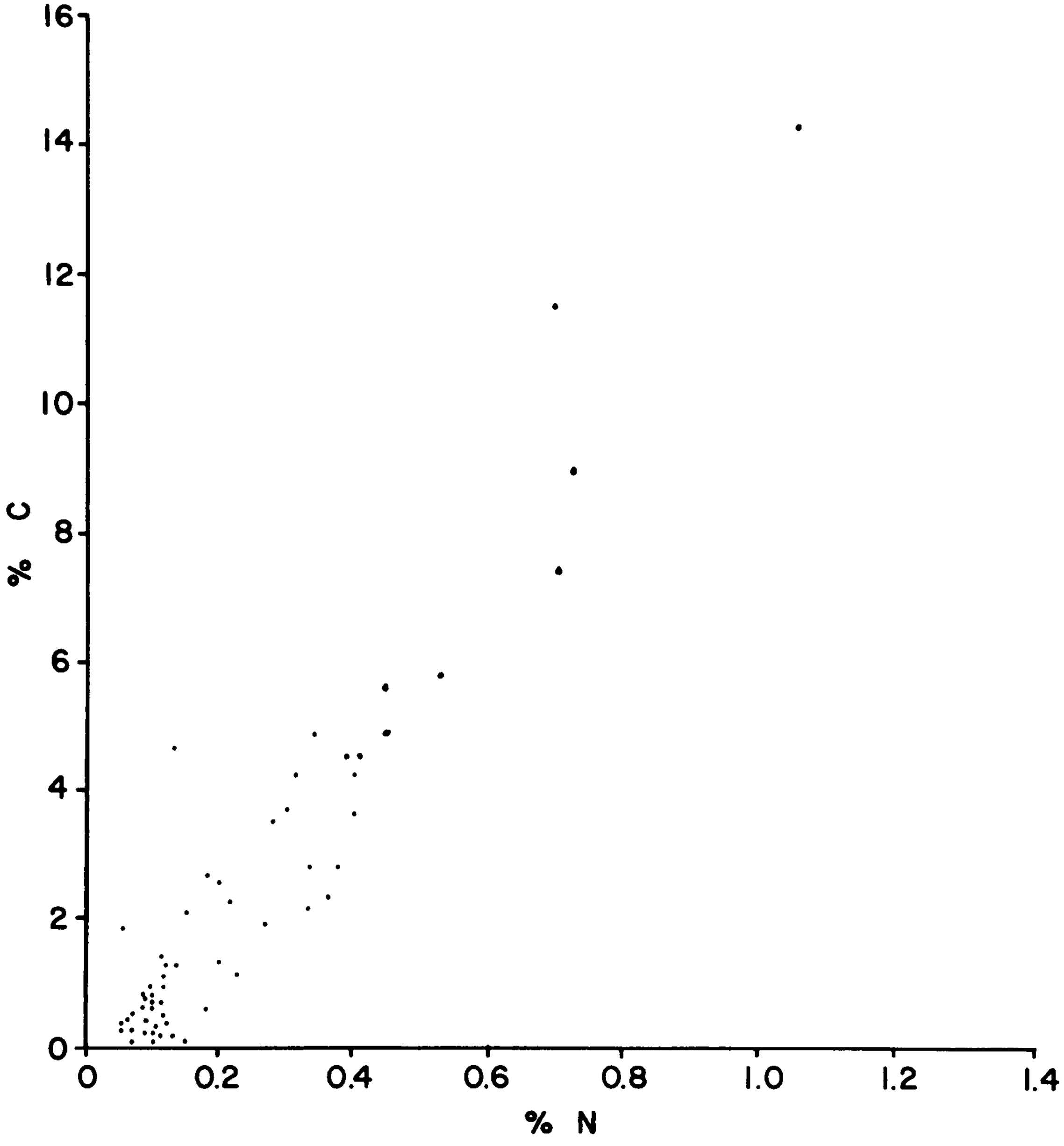

Figure 9

Total N vs. Total C in Marsh Soils from
Georgia, Delaware, and Maine

PART IV: RESPONSE OF SALT MARSH PLANT STANDS TO A PULSE OF AMMONIUM NITRATE

Introduction

Many agricultural and natural ecosystems have been shown to be limited in productivity by available nitrogen. Valiela and Teal (1974) measured an increase in plant growth in a Massachusetts *Spartina* marsh with the addition of nitrogen. Sullivan and Daiber (1974) found a similar response in a Delaware short form *Spartina alterniflora* marsh. Broome et al. (1973) obtained a similar enhancement in short form *S. alterniflora* growth in North Carolina. Near the southern end of the Atlantic coast where *S. alterniflora* dominates the intertidal wetlands, Gallagher (1974) reported a response in the short form but not in the creekbank *S. alterniflora* stands nor in an adjacent *Juncus roemerianus* marsh. Nitrogen availability seems to be limiting in some tidal marsh situations and not in others. There is a need for understanding nutrient regimes in areas where the less abundant plant species grow because of the dredged material disposal problems faced by the U. S. Army Corps of Engineers. The disposal of dredged material on *S. alterniflora* marshes will raise the elevation so that the plants invading the dredged material or those most likely to be successful if planted will be the species which normally occupy only the upper fringes of the marsh.

The investigations reported here were designed to answer the following questions about the response of various salt marsh species along the Atlantic coast from Georgia to Maine to a pulse of nitrogen added as NH_4NO_3.

1. Which stands will respond by increasing in chlorophyll concentration, nitrogen content, or biomass?
2. Are certain depths of application more effective than others in affecting the parameters listed in the question above?
3. As indicated by rhodamine dye disappearance, which soils have the greatest water movement and hence the greatest possibility of nitrogen leaching?

Methods

Plots were established in 17 plant stands along the coast from Georgia to Maine from November 1974 to May 1975. The plot design was a randomized block (4 replicates) where the treatments were nitrogen as NH_4NO_3 mixed with rhodamine WT dye applied below the surface, at 0-5 cm, 5-10 cm, 10-15 cm, and 15-30 cm, plus a control. A solution of NH_4NO_3 was prepared such that nitrogen was injected at the rate of 200 kg N/ha. Injections were made with a 50-ml syringe fitted with a specially constructed 2-mm inside diameter needle sealed at the end but with two lateral openings 5 mm behind the tip. Rhodamine WT dye was added so that 10 ml was added to each 0.10 m^2 plot. At least 30 individual injections were made in each plot during the injection of the volume of 150 ml of solution.

After a period of growth (Table 12), the aerial portions of the plants were harvested and the fresh and dry weight (at 60° C)

Table 12

Date of Establishment and Harvest for Nitrogen Pulse Experiments

Site	Species	Establishment	Harvest
Georgia	*Borrichia frutescens*	Mar	Jun
	Distichlis spicata	Nov, Jan	Jun
	Salicornia virginica	Jan	May
	Spartina cynosuroides	Mar	Aug
	Spartina patens	Mar	Jun
	Sporobolus virginicus	Jan, Mar	Jun
Delaware	*Distichlis spicata*	Sept*, Jan	Jan, Jun
	Juncus gerardi	Sept*, Jan	May, Aug
	Salicornia virginica	Mar	Jun
	Spartina patens	Mar	Aug
Maine	*Juncus gerardi*	May	Aug
	Spartina alterniflora	May	Aug
	Spartina patens	May	Aug

* 1974; all other dates 1975.

determined. Chlorophyll was extracted in acetone (Strickland and Parsons, 1968), and the concentration of chlorophyll A and B was determined using the equations of Arnon (1949). Two cores were taken in each plot to a depth of 35 cm with a piston corer. Both were sectioned 0-5, 5-10, 10-15, and 13-35 cm. One was washed over a 1-mm sieve with seawater and the biomass of the underground macro-organic matter (MOM) determined. The second core was split in half. One half was freeze-dried and ground to pass a 40-mesh sieve. Total nitrogen was determined on the aerial plant material, MOM, and the freeze-dried soil by the Kjeldahl method. Rhodamine was extracted from the other half of the split core. The core segment was placed in a blender with 200 ml of water and the sample dispersed for 2 minutes. The volume was brought up to 250 ml. A 15-ml aliquot was removed and spun for 5 minutes in a table-top centrifuge. The rhodamine WT concentration in the supernate was determined by fluorometry. All statistical methods are described in Sokal and Rohlf (1969).

Results and Discussion

The results of the rhodamine WT dye studies are shown in Tables 13, 14, 15. These data show that the leachable dye did not move away from the injection site rapidly in any of the soils. Since the dye is more likely to move than the inorganic nitrogen, the authors were reassured that the nitrogen was not leached before it could be absorbed. Comparison of the two _D. spicata_ experiments in Georgia (Table 13) indicates most of the dye was lost from the one established in November

Table 13

Relative Rhodamine WT Concentration at 4 Depths in Marsh Soils in Georgia Where the Dye Was Injected at 1 of 4 Depths

Species	Time Format*	Depth, cm: 0 - 5				5 - 10				10 - 15				15 - 35			
		Sample Depth, cm: 0-5	5-10	10-15	15-35	0-5	5-10	10-15	15-35	0-5	5-10	10-15	15-35	0-5	5-10	10-15	15-35
Borrichia frutescens	a	192	96	143	68	103	160	41	163	44	42	47	76	16	17	9	208
Distichlis spicata	b	3	3	4	3	2	3	4	2	3	4	2	3	3	2	4	3
Distichlis spicata	c	297	4	3	3	72	149	45	16	34	14	40	4	22	3	5	13
Salicornia virginica	d	168	40	19	68	98	97	159	127	174	108	217	149	40	36	73	95
Spartina cynosuroides	e	14	26	3	9	7	4	4	5	4	14	42	38	4	4	394	174
Spartina patens	a	115	69	55	28	29	339	166	242	8	54	44	54	2	8	60	150
Sporobolus virginicus	b	97	56	4	3	45	39	7	2	52	114	85	68	26	17	28	534

* a - applied in March - sampled in June
b - applied in November - sampled in June
c - applied in January - sampled in June
d - applied in January - sampled in May
e - applied in March - sampled in August

Table 14

Relative Rhodamine WT Concentration at 4 Depths in Marsh Soils in Delaware

Where the Dye Was Injected at 1 of 4 Depths

Species	Time Format*	Depth, cm: 0 - 5				5 - 10				10 - 15				15 - 35			
		Sample Depth, cm: 0-5	5-10	10-15	15-35	0-5	5-10	10-15	15-35	0-5	5-10	10-15	15-35	0-5	5-10	10-15	15-35
Distichlis spicata	a	258	277	8	2	28	160	40	3	9	111	182	52	9	18	110	452
Distichlis spicata	b	112	26	11	4	43	233	151	2	5	36	151	4	65	25	14	66
Distichlis spicata	c	67	54	6	4	182	36	6	5	12	39	54	5	48	54	29	347
Juncus gerardi	d	112	343	2	2	10	16	4	720	8	25	4	181	4	6	30	3
Juncus gerardi	e	638	277	6	5	51	274	72	5	21	138	638	326	16	14	22	138
Juncus gerardi	f	81	6	5	3	8	11	6	2	10	43	30	19	7	8	67	6
Spartina patens	g	140	50	6	11	17	49	4	4	7	249	289	54	4	20	8	140
Salicornia virginica	h	788	590	172	22	67	898	809	97	29	316	293	22	29	21	13	167

* a - applied in September - sampled in January
b - applied in January - sampled in June
c - applied in September - sampled in June
d - applied in September - sampled in May
e - applied in January - sampled in May
f - applied in January - sampled in August
g - applied in March - sampled in August
h - applied in March - sampled in June

Table 15

Relative Rhodamine WT Concentration at 4 Depths in Marsh Soils in Maine Where the Dye Was Injected at 1 of 4 Depths in May and Sampled in August

	Depth, cm															
	0 - 5				5 - 10				10 - 15				15 - 35			
	Sample Depth, cm															
Species	0-5	5-10	10-15	15-35	0-5	5-10	10-15	15-35	0-5	5-10	10-15	15-35	0-5	5-10	10-15	15-35
Juncus gerardi	34	60	25	5	19	106	11	3	15	126	618	69	29	33	40	80
Spartina alterniflora	265	97	5	2	119	672	33	19	56	359	152	3	68	22	5	68
Spartina patens	202	94	4	2	5	18	4	4	2	33	92	2	6	40	45	85

and harvested in June while much remained when the dye was injected in January. This difference was probably primarily a function of the longer period the dye was exposed to leaching in the plots established in November.

Tables 16, 17, 18 show the results of nutrient enrichment on the aerial biomass of the plants studied. The only clear enhancement in Georgia was in *Salicornia virginica* ($\alpha = 0.01$). In Delaware, *J. gerardi* responded positively to the nitrogen addition in both experiments ($\alpha = 0.05$). The *S. virginica* enrichment also gave positive results in Delaware. None of the enrichment studies in Maine gave positive results. The lack of response in Maine was not unexpected in view of the high ammonium ion levels measured in the soil (Part III). Thus, along the coast, biomass produced was limited by the available nitrogen in only a few instances. Gallagher (1975) earlier found a response in high marsh *S. alterniflora* but none in *J. roemerianus* or creekbank *S. alterniflora*.

Some of the plants which had positive biomass responses and several which did not were tested for nitrogen content to see if added nutrient would change the quality of detritus entering the estuarine food web from these plant stands. Table 19 shows the results of these analyses. The *J. gerardi* in Delaware which showed a biomass response to nitrogen also exhibited a nitrogen content response. The *S. virginicus* stand in Georgia did not show a response in biomass, but the nitrogen content of the treated plants was 1.7 that of the control plants.

Table 16

Mean Standing Crop of Live and Dead Plants (g dry weight/M^2) of Georgia Marsh Plants Receiving a 200 kg/ha Pulse of Nitrogen at 4 Depths

Depth of Treat-ment (cm)	a			b			e		
	Borrichia frutescens			*Distichlis spicata*			*Sporobolus virginicus*		
	Live	Dead	Total	Live	Dead	Total	Live	Dead	Total
Control	428(266)*	136(125)	564(290)	298(66)	332(102)	630(166)	390(76)	76(64)	466(128)
0-5	714(316)	84(52)	798(268)	532(204)	336(116)	868(246)	266(110)	56(44)	322(78)
5-10	606(294)	134(94)	740(356)	604(192)	336(136)	940(316)	238(180)	40(22)	278(192)
10-15	600(372)	114(32)	714(354)	548(192)	260(76)	808(252)	342(174)	30(12)	372(172)
15-35	662(328)	68(28)	730(336)	480(54)	230(150)	710(132)	472(154)	24(2)	496(158)

Depth of Treat-ment (cm)	d			a			c
	Spartina cynosuroides			*Spartina patens*			*Salicornia virginica*
	Live	Dead	Total	Live	Dead	Total	Total
Control	1428.8(686.8)	880.8(96.4)	2309.6(597.2)	924.6(363.2)	458.0(109)	1382.6(258)	106(20)
0-5	1563.6(1414.4)	1082.4(358)	2646.0(1763.6)	826.6(221.8)	3506.0(96)	4332.6(302)	660(230)
5-10	1345.6(574.4)	1044.8(484)	2390.4(678.4)	1172.6(223.8)	359.0(109)	1531.6(272)	836(340)
10-15	1333.6(434.8)	1423.2(560)	2756.8(991.2)	1543.0(183.0)	302.6(221.6)	1845.6(350)	590(156)
15-35	2342.4(1250)	908.4(636)	3250.8(1620)	1220 (906.6)	364.6(119.6)	1584.6(1132)	526(66)

* numbers in parentheses are S.E. values where N=4
a March enrichment - June harvest
b January enrichment - July harvest
c January enrichment - May harvest
d March enrichment - August harvest
e November enrichment - June harvest

Table 17

Mean Standing Crop of Live and Dead Plants (g dry weight/M^2) of Delaware Marsh Plants Receiving a 200 kg/ha Pulse of Nitrogen at 4 Depths

Depth of Treat- ment (cm)	a			b			f	e		
	Distichlis spicata			*Distichlis spicata*			*Salicornia virginica*	*Juncus gerardi*		
	Live	Dead	Total	Live	Dead	Total	Total	Live	Dead	Total
Control	462(60)*	470(88)	932(52)	462(60)	470(88)	932	872(56)	2.0(.6)	120(66)	122(66)
0-5	492(156)	404(8)	896(158)	414(146)	272(136)	686	1062(128)	288(80)	72(78)	360(158)
5-10	572(76)	516(228)	1088(260)	592(292)	352(198)	944	1076(172)	334(72)	102(36)	436(94)
10-15	570(14)	412(42)	982(52)	296(120)	396(124)	692	1082(182)	382(56)	152(88)	534(126)
15-35	654(390)	496(112)	1150(38)	396(302)	436(192)	832	1014(46)	372(72)	180(170)	552(94)

Depth of Treat- ment (cm)	c			d			d		
	Juncus gerardi			*Phragmites communis*			*Spartina patens*		
	Live	Dead	Total	Live	Dead	Total	Live	Dead	Total
Control	60(8)	50(14)	111(22)	1381(536)	2654(691)	4035(610)	742(98)	520(176)	1262(108)
0-5	306(72)	152(58)	458(44)	1328(697)	2735(649)	4063(1110)	632(220)	554(92)	1186(264)
5-10	326(132)	128(36)	454(134)	2054(1269)	1948(637)	4002(1450)	744(352)	652(172)	1396(304)
10-15	312(54)	160(58)	472(74)	1475(1137)	1574(926)	3049(1361)	632(180)	652(190)	1284(308)
15-35	310(92)	160(56)	470(120)	2163(316)	2305(1018)	4468(817)	628(286)	600(138)	1228(236)

* numbers in parentheses are S.E. values where N=4
a September enrichment - June harvest
b January enrichment - June harvest
c January enrichment - May harvest
d March enrichment - August harvest
e September enrichment - January harvest
f March enrichment - June harvest

Table 18

August Mean Standing Crop of Live and Dead Plants (g dry weight/M^2) of Maine Marsh Plants Receiving a 200 kg/ha Pulse of Nitrogen at 4 Depths in May

Depth of treatment (cm)	*Juncus gerardi*			*Spartina alterniflora*			*Spartina patens*		
	Live	Dead	Total	Live	Dead	Total	Live	Dead	Total
Control	90(74)*	506(126)	596(158)	644(412)	52(38)	696(412)	742(308)	276(190)	1018(486)
0-5	72(20)	664(132)	736(144)	620(192)	22(20)	642(192)	608(266)	336(56)	944(242)
5-10	104(148)	672(130)	776(188)	480(286)	170(96)	650(220)	914(296)	480(336)	1394(596)
10-15	156(140)	494(28)	650(154)	574(170)	60(118)	634(224)	736(310)	524(174)	1260(450)
15-35	100(32)	544(110)	644(138)	636(324)	64(28)	700(300)	784(254)	284(58)	1068(224)

* numbers in parentheses are S.E. values where N=4

Table 19

Nitrogen Content of Live Plants and Their Respective Standing Dead Communities After Receiving a 200 kg/ha Pulse of Nitrogen (means expressed as % of dry weight)

	Live		Dead	
	Control	Treated	Control	Treated
Sporobolus virginicus (GA)	(0.89)	(1.53)a	(0.84)	(1.16)a
Spartina cynosuroides (GA)	1.27	1.15	0.91	0.96
Juncus gerardi (DL)	1.26	1.51*	1.68	1.89
Spartina alterniflora (ME)	1.24	1.37	1.31	1.30
Spartina patens (ME)	1.22	1.27	1.11	0.99
(DL)	0.94	0.97	0.87	0.93
Phragmites communis (DL)	1.59	1.23	1.28	1.38

* F distribution value of numbers underlined found to be significant (0.05).

a F distribution value of numbers in parentheses found to be highly significant (0.005).

Since at harvest time it was noted that the chlorophyll content appeared to vary between treatments, the samples were analyzed for chlorophyll A and B (Tables 20, 21, 22). In Georgia the B. frutescens treatments were higher than the control, although biomass differences were not detected. No other statistical differences in chlorophyll content were noted although visual differences were evident. In Delaware, differences in chlorophyll were statistically significant only in the D. spicata treatment and no consistent shifts in the A/B ratio were noted. As with the other parameters measured in the Maine experiments, no increase in chlorophyll or shift in A/B ratio was observed.

Nitrogen may be limiting productivity or affecting plant nutrient quality for grazers or the members of the detrital food web. The evidence from these studies is that this may be true in Georgia for S. virginica, S. virginicus, and B. frutescens but not for the D. spicata, S. cynosuroides, or S. patens stands evaluated. Earlier studies indicated a large response in short S. alterniflora, a possible slight response in creekbank S. alterniflora as evidenced by a change in color in infrared photographs, and no response in J. roemerianus (Gallagher, 1975).

The Delaware experiments showed evidence of enhancement in the J. gerardi, S. virginica, and D. spicata but none in the stands of P. communis or S. patens. Earlier work by Sullivan and Daiber (1974) indicated short form S. alterniflora growth could be enhanced by adding nitrogen.

Table 20

Chlorophyll A (mg chlorophyll/ g fresh weight) and A/B Fraction in Live Marsh Plants from Georgia. Treated Plants Received 200 kg/ha Nitrogen at 1 of 4 Depths

Depth of treatment (cm)	*Borrichia frutescens* [a] A	*Borrichia frutescens* [a] A/B	*Distichlis spicata* [b] A	*Distichlis spicata* [b] A/B	*Salicornia virginica* [c] A	*Salicornia virginica* [c] A/B	*Spartina cynosuroides* [d] A	*Spartina cynosuroides* [d] A/B	*Spartina patens* [a] A	*Spartina patens* [a] A/B	*Sporobolus virginicus* [e] A	*Sporobolus virginicus* [e] A/B
Control	0.085 (.021)*	2.39 (.55)	0.480 (.132)	2.51 (.12)	0.152 (.066)	14.04 (19.44)	0.560 (.320)	2.17 (.20)	0.634 (.094)	2.29 (.05)	0.320 (.072)	2.26 (.12)
0-5	0.186 (.018)	2.43 (.16)	0.602 (.086)	2.51 (.02)	0.189 (.072)	6.37 (.51)	0.550 (.062)	2.12 (.15)	0.734 (.356)	2.25 (.04)	0.504 (.100)	2.17 (.23)
5-10	0.143 (.020)	2.30 (.04)	0.467 (.159)	2.33 (.04)	0.230 (.022)	2.45 (1.94)	0.473 (.160)	2.20 (.05)	0.615 (.109)	2.31 (.27)	0.303 (.140)	1.87 (.23)
10-15	0.176 (.009)	2.63 (.29)	0.750 (.198)	2.40 (.13)	0.234 (.133)	2.85 (2.23)	0.837 (.169)	2.12 (.11)	0.750 (.132)	2.28 (.16)	0.349 (.160)	2.13 (.26)
15-35	0.130 (.068)	3.34 (.79)	0.494 (.138)	2.19 (.33)	0.241 (.068)	3.52 (1.85)	0.400 (.243)	2.14 (.11)	0.546 (.232)	2.24 (.10)	0.368 (.153)	2.16 (.10)

* numbers in parentheses are S.E. values where N=4
a March enrichment - June harvest
b January enrichment - July harvest
c January enrichment - May harvest
d March enrichment - August harvest
e November enrichment - June harvest

Table 21

Chlorophyll A (mg chlorophyll/g fresh weight) and A/B Fraction in Live Marsh Plants from Delaware.

Treated Plants Received 200 kg/ha Nitrogen at 1 of 4 Depths

Depth of Treatment (cm)	Distichlis spicata a		Distichlis spicata b		Juncus gerardi e		Juncus gerardi c		Phragmites communis d		Salicornia virginica f		Spartina patens d	
	A	A/B	A	A/B	A	A/B	A	A/B	A	A/B	A	A/B	A	A/B
Control	0.430 (.106)*	2.22 (.29)	0.430 (.106)	2.22 (.29)	NONE		NONE		0.482 (.191)	2.52 (.17)	0.133 (.012)	2.73 (.25)	0.175 (.083)	2.37 (.33)
0-5	0.729 (.224)	2.24 (.27)	0.584 (.149)	1.94 (.04)	0.451 (.109)	3.24 (.44)	0.560 (.226)	2.13 (.74)	0.546 (.271)	2.73 (.30)	0.140 (.019)	2.44 (.49)	0.388 (.110)	2.37 (.16)
5-10	0.700 (.080)	2.09 (.16)	0.838 (.018)	2.24 (.11)	0.638 (.284)	4.91 (5.18)	0.706 (.112)	2.61 (.52)	0.444 (.140)	2.46 (.23)	0.137 (.016)	2.34 (.80)	0.188 (.040)	2.34 (.02)
10-15	0.892 (.211)	2.26 (.15)	0.720 (.141)	2.05 (.26)	0.600 (.098)	2.81 (.19)	0.587 (.137)	3.01 (.99)	0.536 (.307)	1.43 (1.24)	0.140 (.034)	2.82 (.23)	0.250 (.078)	2.49 (.36)
15-35	0.757 (.131)	2.06 (.23)	1.728 (1.360)	4.13 (2.71)	0.412 (.125)	2.01 (.25)	0.570 (.182)	2.39 (.68)	0.452 (.296)	2.72 (.11)	0.116 (.008)	2.50 (.54)	0.221 (.060)	1.69 (1.15)

* numbers in parentheses are S.E. values where N=4
a September enrichment - June harvest
b January enrichment - June harvest
c January enrichment - May harvest
d March enrichment - August harvest
e September enrichment - May harvest
f March enrichment - June harvest

Table 22

August Chlorophyll A (mg chlorophyll/g fresh weight) and A/B Fraction in Live Marsh Plants from Maine Receiving a 200 kg/ha Pulse of Nitrogen at 4 Depths in May

Depth of Treatment (cm)	*Juncus gerardi*		*Spartina alterniflora*		*Spartina patens*	
	A	A/B	A	A/B	A	A/B
Control	0.364(.255)*	2.87(.90)	0.691(.320)	4.23(3.06)	0.494(.244)	3.20(1.48)
0-5	0.474(.210)	2.23(.85)	0.435(.329)	2.79(.23)	0.546(.178)	2.62(.10)
5-10	0.278(.090)	2.22(.58)	0.391(.219)	2.69(.12)	0.509(.171)	2.69(.06)
10-15	0.388(.125)	2.18(.33)	0.363(.236)	2.10(.60)	0.585(.129)	3.48(1.56)
15-35	0.510(.362)	1.82(.90)	0.448(.170)	2.60(.09)	0.699(.249)	2.44(.11)

* numbers in parentheses are S.E. values where N=4

The number of replicates chosen in these experiments was based on similar studies conducted in Georgia on *S. alterniflora* and *J. roemerianus* (Gallagher, 1975). Variability in several of the species in the study reported in this part of the report proved higher than those studied earlier. If the response of one of the more variable species (*S. alterniflora* in Maine, for example) becomes of immediate interest, intensive studies should be initiated.

PART V: SALT MARSH PLANT GROWTH ON THREE TYPES OF DREDGED MATERIAL

Introduction

During the past two decades large acreages of natural coastal ecosystems have been destroyed by industrial and recreational development. Recently there have been many initiatives to either restore perturbated natural systems or to create new areas to substitute for areas which cannot be restored. The U. S. Army Corps of Engineers has been very interested in developing techniques to vegetate dredged material islands. A problem arises when it is desired to create a marsh on a specific dredged material. Soil testing techniques are not yet available which would enable the prediction of success of each of the several dozen potential species on the various types of dredged material which may be found at numerous coastal environments.

This study was designed to examine the growth of several species of marsh plants on three widely different types of dredged material from the Georgia coast and to compare several methods which could serve as bioassay techniques for testing the ability of various plant species to grow in specific dredged material situations.

Methods

Three types of dredged material were selected which had diverse properties. The first was a coarse sandy material from nearly fresh water; the second was a mixture of fine sand, lumps of silt, and clay from brackish water; and the third was a silt and clay mixture from a saline river. (See Part III for a more detailed description of the collection sites and the materials.) These gave the extremes which are likely to be encountered in the southeast Atlantic coast.

Greenhouse Experiment

In the first experiment, cylindrical plastic trash cans 32.5 cm in diameter and 35.6 cm high were filled with the dredged material and placed in a greenhouse. The greenhouse used was glass with mechanical air circulation but without an evaporative cooler or air conditioning. The use of whitewash and shades over the glass reduced the inside light approximately 50% but reduced internal heating to usually less than 5°C above ambient. This range is well within the conditions experienced in stands of marsh plants. One set (one each of the three types of dredged material) of tubs was left unplanted while others were planted with sprigs of freshly dug plant material from nearby marshes between 24 and 31 July 1974 (Table 23). Each tub was planted at 1/10 of the natural stand density. Each combination of plant and substrate was established in triplicate. Wells made of 1.27-cm-diameter PVC tubing were placed vertically to a depth of 10 and 25 cm in each container. During the study the water in the wells was tested for pH and salinity. The containers of plants were watered with fresh water as needed from above (to wash accumulated salt on the plants back to the soil) to keep the soil near field capacity above the 10-cm depth and saturated below that. These soil conditions approximated those near mean low water in the natural marsh.

Table 23

Plant Species Used in the Greenhouse and Dike Studies of Substrate Response

Species planted	Greenhouse study	Dike study lower level	Dike study upper level
None	X		
Borrichia frutescens	X	X	X
Distichlis spicata	X	X	
Iva frutescens	X		
Spartina cynosuroides	X		
Spartina patens	X		
Sporobolus virginicus			X

Particle density was determined in August and soil bulk density profiles were measured in July 1974 and in March 1976. Particle density was calculated from weights obtained when soil displaced water from a volumetric flask. Bulk density was obtained by weighing dried cores of known volume. Soil carbon was determined with a Leco Carbon Determinator according to the method described by Gallagher, Plumley, and Perkins (in press). Soils were allowed to dry to the point where no water was standing in the shallow wells and water infiltration was measured using a field rainfall simulator as a water source. The device was built from a 10-cm section of 12-cm-diameter PVC pipe. A solid bottom was perforated with 21 gauge hypodermic needles. A similar size diameter aluminum pipe with a sharp edge was pushed into the soil so that the outlet pipe was at ground level. The PVC pipe was placed above the aluminum section and water added to the PVC tube from a separatory funnel suspended above it. A constant head was maintained in the PVC tube so that the drop size and flow rate remained constant and produced a flow rate of 2.5 cm per pour. Runoff was collected in a bottle placed at the outlet pipe. Infiltration was calculated as the difference between water added and runoff. Samples of the dredged material were air-dried and subjected to analysis according to the standard methods used by the Plant and Soil Testing Laboratory at the University of Georgia. Total nitrogen was determined by Kjeldahl analysis.

Stem counts were taken frequently during the course of the experiment. Chlorophyll content of the _S_. _patens_ and _D_. _spicata_ growing on the three substrates was determined in July and August 1975 by the method described by Arnon (1949). Aerial and underground biomass were determined upon termination of the experiment in March 1976.

Field Experiment

A second experiment with the three types of dredged material was established in the field in March 1975. The purpose of this study was to more closely simulate the actual situation where a dredged material would be placed in the intertidal zone in a marsh.

Triplicate trash containers, like those used in the previous experiment, were filled with each of the three types of dredged material and buried in an intertidal dredged material pile so that they were inundated by spring tides. Holes were punched in the bottom of the plastic trash containers in order to allow drainage. Freshly dug sprigs of *D. spicata* were planted in each container.

In order to test for the effect of reduced drainage due to the containers, pits were dug at the same level; the vertical sides were lined with polyethylene; and triplicate pits were filled with the three types of dredged material. These pits had approximately twice the area of the trash containers. Half of each pit was planted with *D. spicata* and the other half with *B. frutescens*. A second series of pits were similarly dug and filled at a higher elevation which was subject to only the highest spring tides. Half of each pit was planted with *S. virginicus* and half with *B. frutescens*.

Soil pH was determined; soil bulk density profiles taken; rainfall infiltration measured; and in March 1976 the experiment terminated.

Aerial samples of plants were harvested and dried to a constant weight at 60°C. Cores of the soil were taken from each plot for root biomass determination and soil carbon evaluation. All statistical procedures used were outlined by Sokal and Rohlf (1969).

Results and Discussion

Greenhouse Study

Stem density. In terms of numbers of live stems per square meter, *D. spicata* reached maximum growth when on silt and clay (Figures 10, 11, 12). *D. spicata* was relatively successful on the other two substrates as well. *S. patens* experienced its most successful growth on sand and clay with relatively good growth on sand. *B. frutescens*, *I. frutescens*, and *S. cynosuroides* grew only on sand, but not with any significant success. Since these environmental conditions simulated the low intertidal zone, the poor aeration which existed in the fine-textured soils was probably the cause of the failure of *B. frutescens* and *I. frutescens* to grow well under these conditions. These plants grow high in the intertidal zone in natural marshes. Whether the problem is one of low oxygen directly or the accumulation of toxic substances (H_2S, for example) is purely a matter of speculation.

Biomass. Aerial and root biomass data (Table 24) based on the March 1976 harvest paralleled the stem density counts. *Distichlis spicata* achieved its greatest biomass on silt and clay, while *S. patens* had the greatest biomass on sand and clay. *Borrichia frutescens*, *I. frutescens*, and *S. cynosuroides* showed live aerial

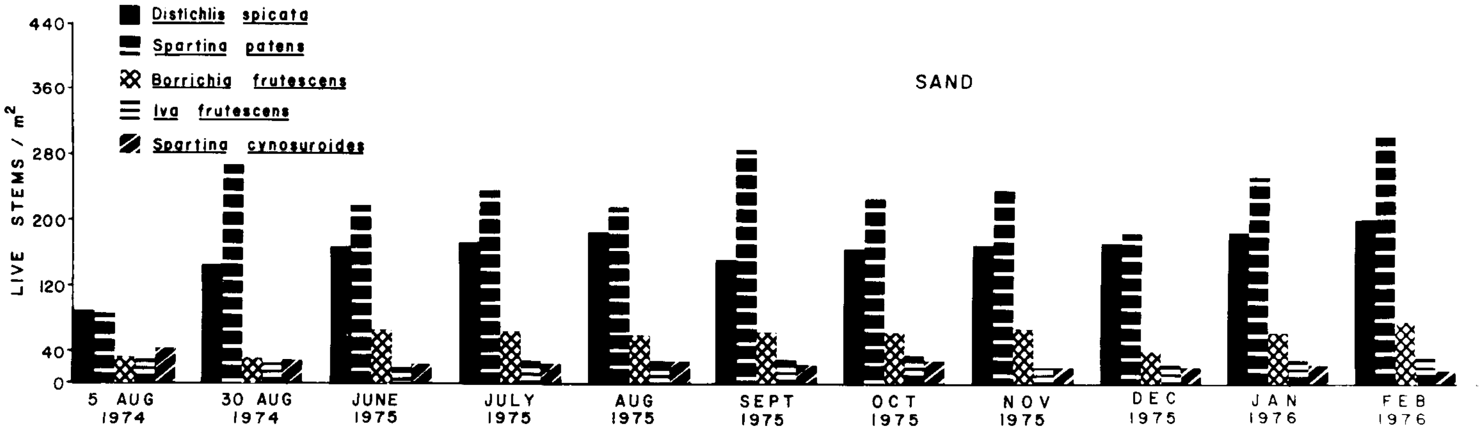

Figure 10

Live Stems per m^2 of Various Marsh Plants Grown in the Greenhouse on a Sandy Dredged Material Held within Trash Containers

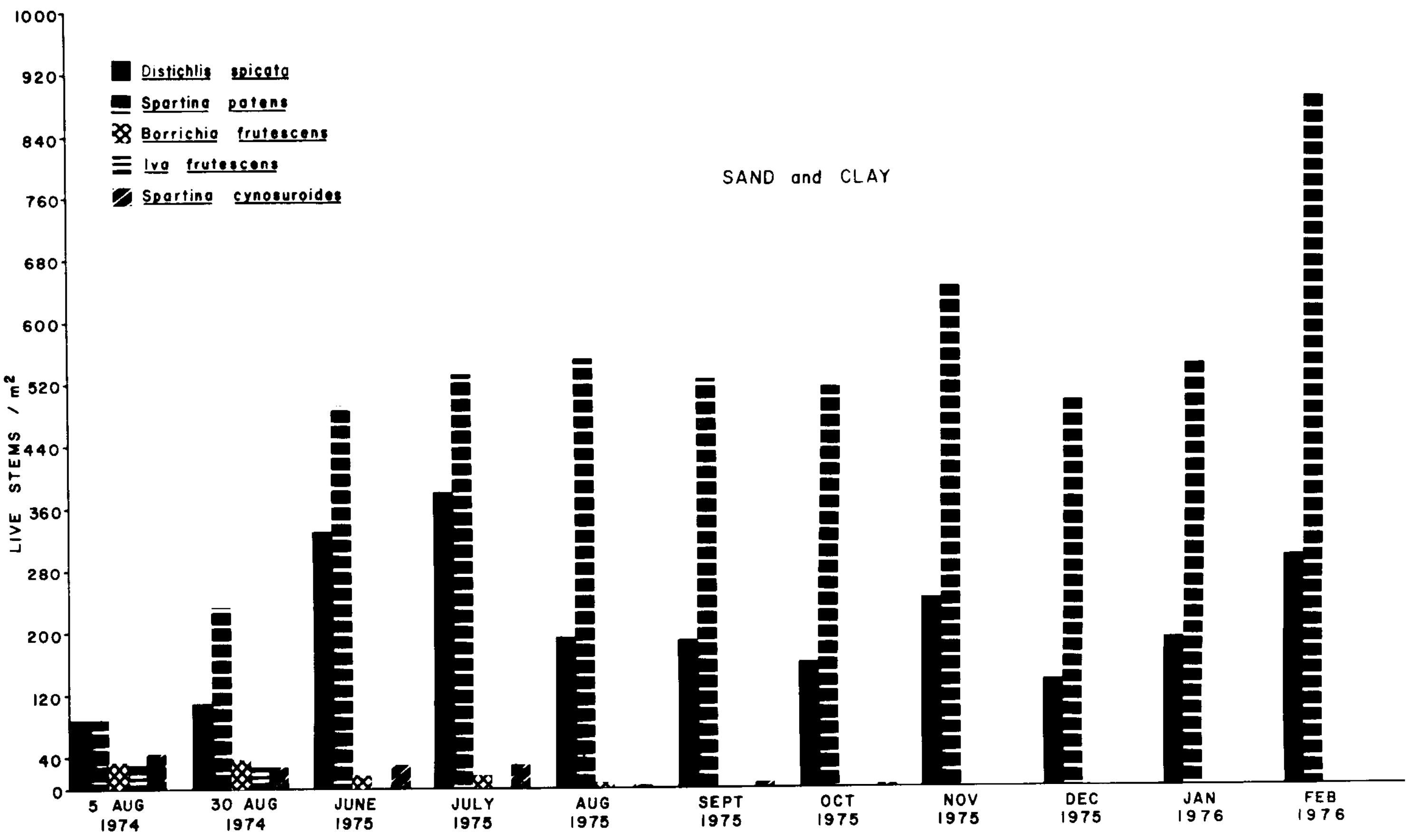

Figure 11

Live Stems per m^2 of Various Marsh Plants Grown in the Greenhouse on a Sand and Clay Dredged Material Held within Trash Containers

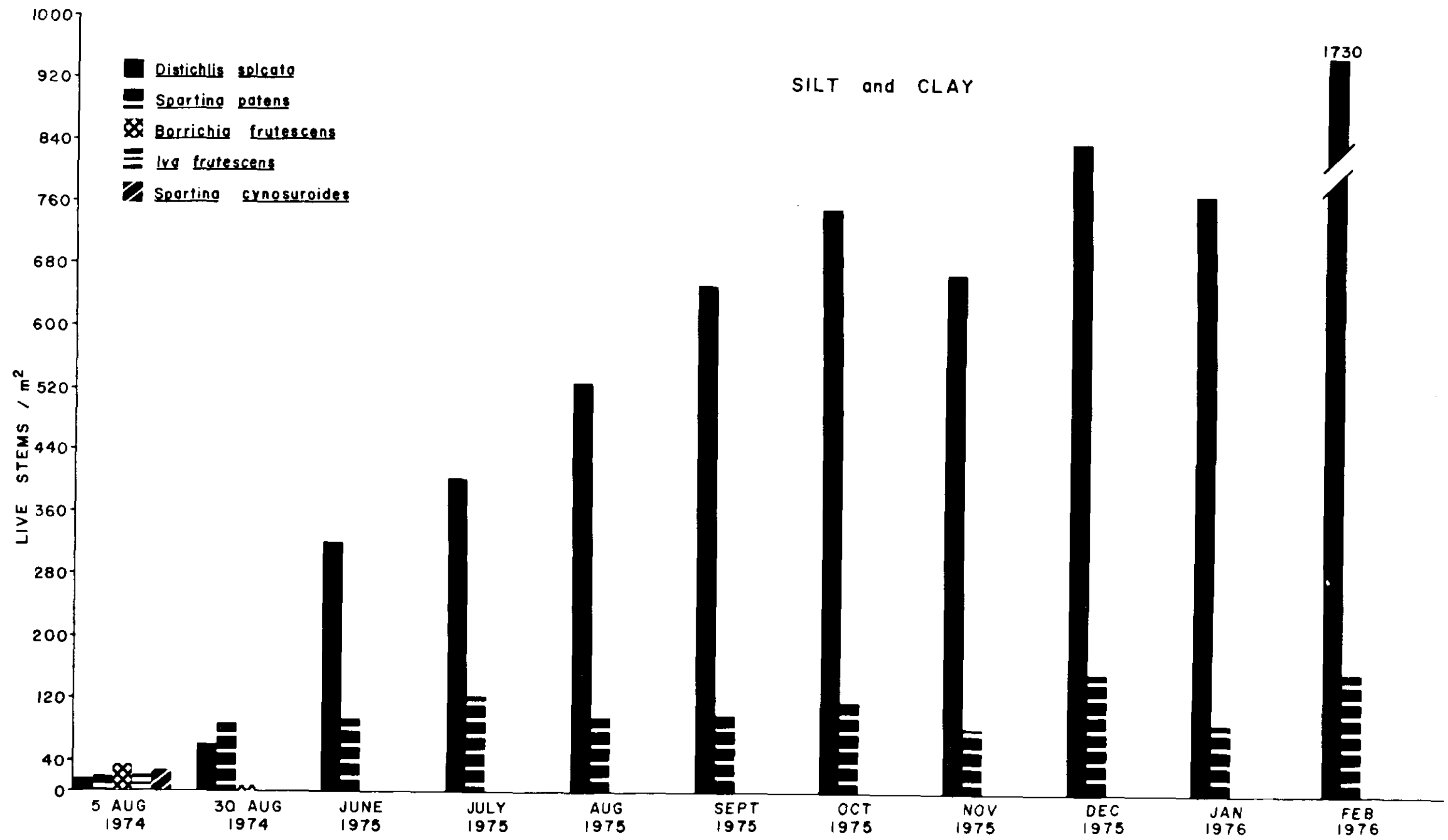

Figure 12

Live Stems per m^2 of Various Marsh Plants Grown in the Greenhouse on Silt and Clay Dredged Material Held within Trash Containers

Table 24

Aerial and Root Biomass (g/m^2)* of Greenhouse Plant Material Based on March 1976 Harvest

Species	Silt and Clay			Sand			Sand and Clay		
	Live Stems	Dead Stems	Roots	Live Stems	Dead Stems	Roots	Live Stems	Dead Stems	Roots
Distichlis spicata	257.33	22.40	213.47	22.70	39.53	64.05	53.33	103.00	168.60
Spartina patens	68.35	47.93	67.40	22.67	57.73	147.37	246.00	90.00	272.57
Borrichia frutescens	0.00	16.23	15.07	65.00	20.97	48.17	0.00	20.73	8.17
Iva frutescens	0.00	27.10	74.00	25.00	4.20	21.10	0.00	1.07	1.70
Spartina cynosuroides	0.00	43.30	67.13	0.67	101.13	79.63	0.00	217.67	154.57

* Dry weight

biomass only on sand in March. Even though there were relatively few live stems with a correspondingly low biomass, the root biomass for S. cynosuroides in all three substrates appeared to be significant. Results of analysis of variance (Table 25) showed that no significant difference occurred in total aerial biomass for any species on the three substrates tested except for the woody plant B. frutescens where the greatest biomass was on the sand and the other two substrates were lower. There was, however, a significant difference in the biomass of live D. spicata among the three substrates. A Student-Newman-Keuls (SNK) range multiple test indicated the growth was best on the silt and clay while the other two substrates did not differ.

Root biomass did not differ significantly among the three substrates for S. cynosuroides and D. spicata; however, differences did occur among S. patens, B. frutescens, and I. frutescens. Root biomass in S. patens was greatest in the sand and clay, less on the sand, and least on the silt and clay. This may be expected because the natural haibtat of S. patens in Georgia is a high sandy marsh or a low dune area. The sand-clay substrate had high fertility while still retaining good drainage. Borrichia frutescens, which normally grows at the upper fringes of the marsh, produced the most root growth in the sand soil. Surprisingly, I. frutescens, which also lives on the marsh fringe, produced a large amount of roots in the silt and clay dredged material.

Chlorophyll. Chlorophyll content of D. spicata and S. patens was significantly higher on the silt and clay than on the other two

Table 25

Results of Analysis of Variance of Aerial and Root Biomass from Plants Grown on Three Substrates in the Greenhouse Study

Species	Comparison		
	Total Aerial Biomass	Live Aerial Biomass	Root Biomass
		F-values	
Borrichia frutescens	7.810 *	1.293 N.S.	11.450 **
Distichlis spicata	2.770 N.S.	5.420 *	1.274 N.S.
Iva frutescens	1.490 N.S.	1.749 N.S.	12.320 **
Spartina cynosuroides	4.411 N.S.	3.496 N.S.	0.815 N.S.
Spartina patens	3.503 N.S.	1.606 N.S.	9.514 *

* Significant at 0.05 level
** Significant at 0.01 level
N.S. Not significant

substrates (Table 26). This was probably due to the higher nitrogen content of this material. The highest chlorophyll content of plants grown on sand was observed in _D_. _spicata_. The above two species were selected for chlorophyll analysis because it was only in these two species that significant growth occurred on all three substrates.

Bulk density. Bulk densities for substrates with and without plants appear in Table 27. A comparison of the bulk density for the combined values for each substrate at harvest with the initial values shows an increase in bulk density for silt and clay (0.390 to 0.443), a decrease in sand (1.503 to 1.414), and a decrease in sand and clay (1.494 to 1.335). Results of the Student's t-test showed that the above differences are significant. All comparisons with significant t-values are listed in Table 28. Results of particle density determinations are as follows: sand, 2.650 $\pm$ 0.200 g/cm^3; silt and clay, 2.693 $\pm$ 0.343 g/cm^3; and sand and clay, 2.456 $\pm$ 0.060 g/cm^3.

Carbon. The results of the carbon analyses are listed (Table 29). A comparison of means utilizing the Student's t-test showed the following significant differences: initial sand and clay higher than _S_. _patens_ on sand and clay (t = 3.500); initial silt and clay higher than _D_. _spicata_ on silt and clay, 1976 (t = 4.243); _S_. _cynosuroides_ on sand and clay, 1976, higher than control, 1976, sand and clay (t = 2.460); _I_. _frutescens_ on sand, 1976, higher than control sand, 1976 (t = 3.040); and initial sand higher than control sand, 1976 (t = 43.412). All other comparisons resulted in t-values which were not significant. The reasons for some of the apparent discrepancies in

Table 26

Results of the SNK Range Test on Analysis of Variance of Chlorophyll Values for *Spartina patens* and *Distichlis spicata* on Three Types of Dredged Material in the Greenhouse Study

Species	Substrate	$\bar{X}$
Spartina patens	Sand	0.330
Spartina patens	Sand and clay	0.431
Distichlis spicata	Sand and clay	0.438
Distichlis spicata	Sand	0.868
Distichlis spicata	Silt and clay	1.164
Spartina patens	Silt and clay	1.246

NOTE: Collections were on 22 July and 25 August 1975.
Mean chlorophyll values in milligrams chlorophyll per gram tissue.
Bars connect rates which are indistinguishable by the Student-Newman-Keuls range test.

Table 27

Means and Standard Deviation of Bulk Densities (g/cm^3) for Dredged Material in Greenhouse Study

Species	Bulk Density					
	N	Silt and Clay	N	Sand	N	Sand and Clay
Initial (July 1974)	21	0.390 ± 0.050	21	1.503 ± 0.102	21	1.494 ± 0.154
Control (March 1976)	7	0.434 ± 0.077	8	1.507 ± 0.180	8	1.323 ± 0.168
Spartina patens	7	0.470 ± 0.097	9	1.389 ± 0.106	7	1.402 ± 0.127
Borrichia frutescens	8	0.420 ± 0.080	9	1.407 ± 0.175	8	1.319 ± 0.197
Iva frutescens	8	0.463 ± 0.070	9	1.308 ± 0.174	9	1.418 ± 0.116
Spartina cynosuroides	7	0.448 ± 0.048	6	1.393 ± 0.238	8	1.230 ± 0.128
Distichlis spicata	8	0.400 ± 0.040	9	1.331 ± 0.249	9	1.316 ± 0.181
Combined (March 1976)	45	0.443 ± 0.070	50	1.414 ± 0.172	49	1.335 ± 0.161

NOTE: Cores from depths of 0-5, 5-10, and 10-15 cm were combined.
Samples were collected 31 July 1974 (initial) and 2 March 1976.
N = number of samples.

Table 28

Results of t-test for Differences in Mean Bulk Densities for Greenhouse Dredged Material

Comparison	t-value
Initial silt and clay vs combined silt and clay (1976)	4.308 **
Initial sand vs combined sand (1976)	2.213 *
Initial sand and silt vs combined (1976)	3.903 *
Sand (1976) vs sand and clay (1976)	3.434 **
Initial sand (1976) vs *Iva frutescens* on sand (1976)	2.301 *
Spartina patens on silt and clay (1976) vs initial silt and clay	2.840 **
Spartina patens on sand (1976) vs initial sand	3.300 **
Iva frutescens on silt and clay (1976) vs initial silt and clay	3.131 **
Iva frutescens on sand (1976) vs initial sand	3.844 **
Spartina cynosuroides on sand and clay (1976) vs initial sand and clay	4.306 **

NOTE: Only significant differences are listed.
Samples collected 31 July 1974 (initial) and 2 March 1976.

* Significant at 0.05 level.
** Significant at 0.01 level.

Table 29

Means and Standard Deviation of Carbon Values for Dredged Material in Greenhouse Study

Species	% Carbon					
	N	Silt and Clay	N	Sand	N	Sand and Clay
Initial (July 1974)	12	3.309 ± 0.225	9	0.048 ± 0.003	12	0.599 ± 0.179
Control (March 1976)	12	3.037 ± 0.842	12	0.001 ± 0.002	12	0.462 ± 0.323
Spartina patens	12	2.819 ± 1.051	12	0.011 ± 0.016	12	0.334 ± 0.190
Borrichia frutescens	12	2.893 ± 1.124	12	0.014 ± 0.029	12	0.522 ± 0.308
Iva frutescens	12	2.816 ± 0.896	12	0.098 ± 0.110	12	0.492 ± 0.267
Spartina cynosuroides	12	2.868 ± 1.032	12	0.010 ± 0.022	12	0.712 ± 0.143
Distichlis spicata	12	2.473 ± 0.644	12	0.046 ± 0.060	12	0.412 ± 0.343
Combined (March 1976)	72	2.818 ± 0.927	72	0.030 ± 0.062	72	0.479 ± 0.289

NOTE: Samples were collected 31 July 1974 (initial) and 2 March 1976.
Values in % carbon.
N = number of samples.

the data are not clear.

Salinity. Soil water salinity differed significantly in the three substrates (Table 30). In addition, water obtained from silt and clay and sand showed a decrease in salinity from 1974 to 1975 in both long and short tubes. The change in the short tube in sand was not, however, significant (Table 31). Water from sand and clay showed an increase in salinity from 1974 to 1975 (Table 30).

pH. The results of the pH determination showed, in only two instances, differences between water from long and short tubes. In 1974, the pH of water from the short tube in silt and clay was 7.60 as compared to 7.44 in the long tube (Table 30). Also in 1974, the pH of water from the short tube in sand was 7.41 as compared to 7.09 in the long tube. In comparing the various substrates, pH of the water obtained from both long and short tubes in sand and clay was significantly lower than that obtained from long and short tubes in the other two substrates. The t-values are highly significant in all comparisons for 1974 and 1975.

In observing the changes in pH in a given substrate from year to year, the pH of soil water from the long tube in silt and clay was significantly higher in 1975 as compared to 1974. In sand and clay there was a significant decrease in soil water pH from 1974 to 1975 in both long and short tubes. No significant changes occurred in soil water pH from sand between 1974 and 1975. Significant differences occurred between silt and clay and sand in both long and short tubes for 1974 and 1975.

Table 30

Means and Standard Deviations of pH and Salinity for Water Recovered from Long and Short Tubes in Three Types of Dredged Material from the Greenhouse Study

Dredged Material	Year	Short Tube N	Short Tube pH	Short Tube N	Short Tube Sal (‰)	Long Tube N	Long Tube pH	Long Tube N	Long Tube Sal (‰)
Silt and clay	1974	42	7.60 ± 0.07	21	32.2 ± 4.6	42	7.44 ± 0.30	63	31.4 ± 2.6
	1975	21	7.61 ± 0.25	15	24.5 ± 6.4	21	7.75 ± 0.35	21	25.5 ± 4.9
Sand	1974	26	7.41 ± 0.27	18	2.4 ± 0.8	42	7.09 ± 0.27	83	3.6 ± 1.1
	1975	21	7.36 ± 0.47	5	2.0 ± 0.7	21	7.07 ± 0.35	16	2.5 ± 1.1
Sand and clay	1974	37	5.49 ± 1.92	22	8.6 ± 1.7	42	5.83 ± 1.86	64	7.8 ± 3.3
	1975	21	4.04 ± 1.06	1	10.0 -	21	4.47 ± 1.11	2	12.0 ± 0.0

N = Number of samples.

Table 31

Results of Student's t-test to Determine Differences in Mean Salinity and pH for Dredged Material from the Greenhouse Study

Parameter	Comparison		t-value: Short tube	t-value: Long tube
Salinity	Silt and clay (1974) vs silt and clay (1975)		4.201 ***	7.070 ***
	Sand (1974) vs sand (1975)		0.335 N.S.	3.662 **
	Sand (1974) vs sand and clay (1975)		14.215 ***	10.923 ***
pH	Silt and clay (1974) vs silt and clay (1975)		1.301 N.S.	3.669 **
	Sand (1974) vs sand (1975)		1.462 N.S.	1.509 N.S.
	Sand and clay (1974) vs sand and clay (1975)		3.187 **	3.079 **
	Silt and clay (1974) vs sand (1974)		4.336 ***	5.680 ***
	Silt and clay (1974) vs sand and clay (1974)		7.119 ***	5.539 ***
	Sand (1974) vs sand and clay (1974)		5.049 ***	4.346 ***
pH	Silt and clay (1975) vs sand (1975)		2.150 *	6.327 ***
	Silt and clay (1975) vs sand and clay (1975)		15.049 ***	12.980 ***
	Sand (1975) vs sand and clay (1975)		13.126 ***	10.289 ***
	Silt and clay (1974)	Short tube vs long tube	3.383 ***	
	Silt and clay (1975)	Short tube vs long tube	1.502 N.S.	
	Sand (1974)	Short tube vs long tube	4.782 ***	
	Sand (1975)	Short tube vs long tube	2.266 N.S.	
	Sand and clay (1974)	Short tube vs long tube	0.686 N.S.	
	Sand and clay (1975)	Short tube vs long tube	1.289 N.S.	

N.S. Not significant.
* Significant at 0.05 level.
** Significant at 0.01 level.
*** Significant at 0.001 level.

Infiltration. The results of the infiltration study were quite variable. As one would expect, the coarse sand had the highest percentage of infiltration. In only one sand container was an infiltration value of less than 100% achieved (79.4%) which led to a mean of 95.6% with a standard deviation of 20.2% for infiltration on sand (Table 32). Sand and clay, and silt and clay showed much variation. The variation of silt and clay can be explained in part by the extensive growth of algae on the surface of the substrate in some of the containers thus preventing the infiltration of rainfall. On containers lacking the algal mat, percent infiltration was as high as 100%. The variation in percent infiltration on sand and clay containers can be explained in part by the fact that the surface of the sand and clay became extremely hard, thus preventing the influx of significant amounts of water. Even though the results were somewhat variable, significant differences between some of the substrates were observed (Table 32). Plant growth did not appear to have any effect on the rate of infiltration on any of the substrates.

Intertidal Field Study

Biomass. The results of the harvesting of the intertidal field study are shown in Table 33. Since no significant differences were seen between the tubs and lower level pits, only the pits are represented. *Borrichia frutescens* did not survive at the lower elevation. The *D. spicata* plants survived on all three substrates, but aerial biomass was greater ($\alpha = 0.08$) on the sand and clay substrate. Underground biomass differences were less clear and the probability of the

Table 32

Results of Simulated Rainfall on Three Types of Dredged Material in Greenhouse Study

Dredged material	N	Mean and Standard Deviation % Water Content	% Infiltration
Silt and clay	20	60.0 ± 4.2	28.6 ± 36.1
Sand	21	7.5 ± 2.1	95.6 ± 20.2
Sand and clay	21	18.0 ± 5.5	41.9 ± 31.0

Results of t-test*

Comparison	t-value
% Infiltration	
Silt and clay vs sand	7.380 ***
Silt and clay vs sand and silt	1.268 N.S.
Sand and silt vs sand	6.700 ***

* N.S. Not significant.
*** Significant at 0.001 level.

NOTE: Percent water content of dredged material refers to the water content at time of application of rainfall. Infiltration expressed as percentage infiltrated from total amount applied. Time of application, 5 minutes; mean amount of water applied per container, 440 ± 46 ml.

Table 33

Aerial Biomass and Underground Biomass for Intertidal

Dredged Material Revegetation Study, March 1976

			Aerial Biomass(g/m^2)*			Underground Biomass(g/m^2)*		
Level	Species		Sand	Sand and Clay	Silt and Clay	Sand	Sand and Clay	Silt and Clay
Lower	*Borrichia*	L						
	frutescens	D		no survival			no survival	
		T						
	Distichlis	L	77.0	168.3	10.2			
	spicata	D	18.0	40.8	24.3			
		T	95.0	209.8	34.5	819.4	1555.6	857.6
Upper	*Borrichia*	L	0.0	2.6	0.0			
	frutescens	D	0.0	4.3	3.8			
		T	0.0	6.9	3.8	0.0	2109.4	243.1
	Sporobolus	L	48.6	172.3	3.2			
	virginicus	D	18.9	91.3	17.4			
		T	67.5	263.5	20.7	684.0	2479.2	350.7

NOTE: L - live
D - dead
T - total.

* dry weight.

growth being significantly greater on the sand and clay substrate was much less ($\alpha = 0.30$). The root/shoot ratios were 8.62, 7.42, and 24.85 for the sand, sand and clay, and silt and clay substrates, respectively. Resource allocation to aerial and underground parts was not different for the two dominantly sandy types of dredged material, but more was placed in root and rhizome development on the heavier textured material.

In the upper tidal level, differences between substrates were much clearer, perhaps because at the lower level the tidal water moderated the influence of the substrates. *Sporobolus virginicus* grew on all three substrates, but the aerial growth was much greater on the sand and clay mixture ($\alpha = 0.01$) than on the other two sediments. Underground biomass was likewise much greater on the sand and clay mixture. *Borrichia frutescens* did not survive on the sand and produced about 10 times more underground biomass on the sand and clay mixture than on the silt and clay. In March the differences in underground biomass were much more dramatic than those of the aerial portions of the plants.

pH. The poor growth on the silt and clay was predictable based on expected pH changes (Table 34). In the upper tidal level, the sand had a pH of 6.59, the sand and clay mixture a pH of 5.80, and the silt and clay, 3.55. The pH of 7.30 in buffer indicates a fairly large acid reserve which combined with nearly 3% carbon content usually results in the development of a "cat clay" problem. At the lower tidal level, all three substrates had pH values above 7.00.

Table 34

Chemical Properties of Dredged Material from Georgia*

Material	pH^W	pH^B	P	K	Ca	Mg	Na	Fe	Mn	Cl	NO_3	Total N	Total C	NH_4
Sand	8.4	8.00	9	25	300	60	140	9	2	56,700	3	0.08	0.00	6
Sand and clay	5.6	7.35	27	25	720	310	360	49	7	17,000	18	0.08	0.40	17
Silt and clay	7.4	7.30	2	1200	5580	1980	11900	2	33	184,300	13	0.36	2.97	41

* Total C and N are in %; others are in ppm.

In view of the relatively poor growth of plants on the sand and clay in the greenhouse, the success of the plants in the field study was at first surprising. When the substrate profiles in the tubs in the greenhouse were compared with those in the field and with the pits, differences which could account for the differential response were noticed. In the greenhouse tubs the soils were held near filled capacity and no natural rainfall reached the soil. Furthermore, since water was added frequently in small quantities, the substrate did not dry out and thus did not produce conditions conducive to rapid leaching during the next watering. At the field sites high in the intertidal zone the substrate dried due to evapotranspiration and conditions were thus ideal for leaching by rainfall. At the end of the experiment in the greenhouse, the lenses of clay mixed in the sand were intact and nearly the same as when the experiment was initiated. At the field sites, the silt and clay was leached to the lower part of the profile. In the greenhouse material there had been relatively little degradation of the particulate organic material, but at the field site it was almost all oxidized. The problems regarding the cat clay situation which would be affected by vertical placement in the intertidal zone were considered, but not the soil-forming processes of eluviation and illuviation working so rapidly to modify the substrates.

Table 35 shows the percent carbon in the three types of dredged material under the various plant and elevation conditions. The variations within one dredged material were greater than differences between

Table 35

Carbon Value (% Carbon) of Dredged Material from Plots in Field Study, March 1976

Level	Species	Depth cm	% Carbon* Sand	Sand and Clay	Silt and Clay
Lower	*Distichlis*	0-5	0.082 (.085)	0.141 (.054)	2.290 (.355)
	spicata	5-10	0.290 (.295)	0.166 (.363)	2.100 (.338)
		10-15	0.026 (.036)	0.007 (.016)	2.223 (.502)
		15-35	0.035 (.069)	0.016 (.019)	2.224 (.345)
	Integrated value		0.077	0.054	2.216
Upper	*Borrichia*	0-5	0.182 (.201)	0.186 (.166)	2.121 (.600)
	frutescens	5-10	0.115 (.150)	0.016 (.013)	2.465 (.532)
		10-15	0.005 (.007)	0.043 (.050)	2.340 (.441)
		15-35	0.009 (.022)	0.038 (.052)	2.281 (.571)
	Integrated value		0.048	0.057	2.293
	Sporobolus	0-5	0.096 (.073)	0.128 (.006)	1.992 (.957)
	virginicus	5-10	0.093 (.135)	0.067 (.064)	2.311 (.627)
		10-15	0.018 (.012)	0.504 (.653)	2.764 (.684)
		15-35	0.063 (.099)	0.182 (.232)	2.686 (.524)
	Integrated value		0.066	0.204	2.544

* Numbers in parentheses are standard deviation.

plant species on a single dredged material. When compared with the dredged material kept in the greenhouse, there were no significant differences between the sand or the silt and clay, but the sand and clay was lower in the field study than in the greenhouse.

Need for Field Bioassay

The apparent necessity to test each dredged material under each set of environmental conditions prompted the design and test of a field bioassay unit depicted in Figure 13. Holes were drilled in the bottom of the bucket to provide drainage. The 0.83-cm hardware cloth top altered the aerial environment little, but prevented raccoons and other large animals from destroying experimental plots. A slot was cut to allow free access of tidal water, snails, crabs, and other small animals. Following the period of implantation in the natural marsh, the buckets were removed and transported to the laboratory where appropriate measurements were made on above-and below-ground plant growth.

Summary

The studies in the greenhouse and field show that at this time predicting which plants will grow on a particular dredged material under a given water salinity and given intertidal elevation requires a local bioassay. With this in mind, a unit was designed which could be filled with dredged material and planted with sprigs at the lab, carried to the field in a truck or boat, implanted at the site, and similarly removed for evaluation after an incubation period. This

Figure 13

Bucket Modified for Dredged Material-Plant Interaction Studies type of assay should be conducted prior to dredging. Based on the results of the assay, decisions could be made relative to the optimum elevation in the tidal zone for disposal of the dredged material, and the plant species which would show optimal growth at that elevation.

PART VI: MARSH PLANT ROOT GROWTH IN NATURAL SOIL AND DREDGED MATERIAL: A BIOASSAY APPROACH

Introduction

Establishing marshes on dredged material has positive effects on the dredged material disposal site and the surrounding area. Aerial production of plants contributes through the detritus food web to the surrounding estuary. The root system stabilizes the substrate thus reducing erosion, produces carbon sources for microbial flora, and through the interaction with the substrate, creates soil environmental conditions suitable for the development of a typical natural marsh fauna. Because of the importance of the root systems, it is desirable to predict to what extent they will develop in various substrates under various conditions of temperature and salinity. A bioassay chamber was designed in which to test the root growth of different plants in various types of dredged material under various environmental conditions. The results of the tests are reported in this section.

Methods

Experimental Unit

The bioassay chamber is shown in Figure 14. The natural soil chambers were 13 cm long while those for the experimental soil were 10 cm in length. Both were 7.5 cm in diameter. The upper part of the chamber was used to remove cores of natural soil with the plants in place from established marshes. The lower portion of the chamber was

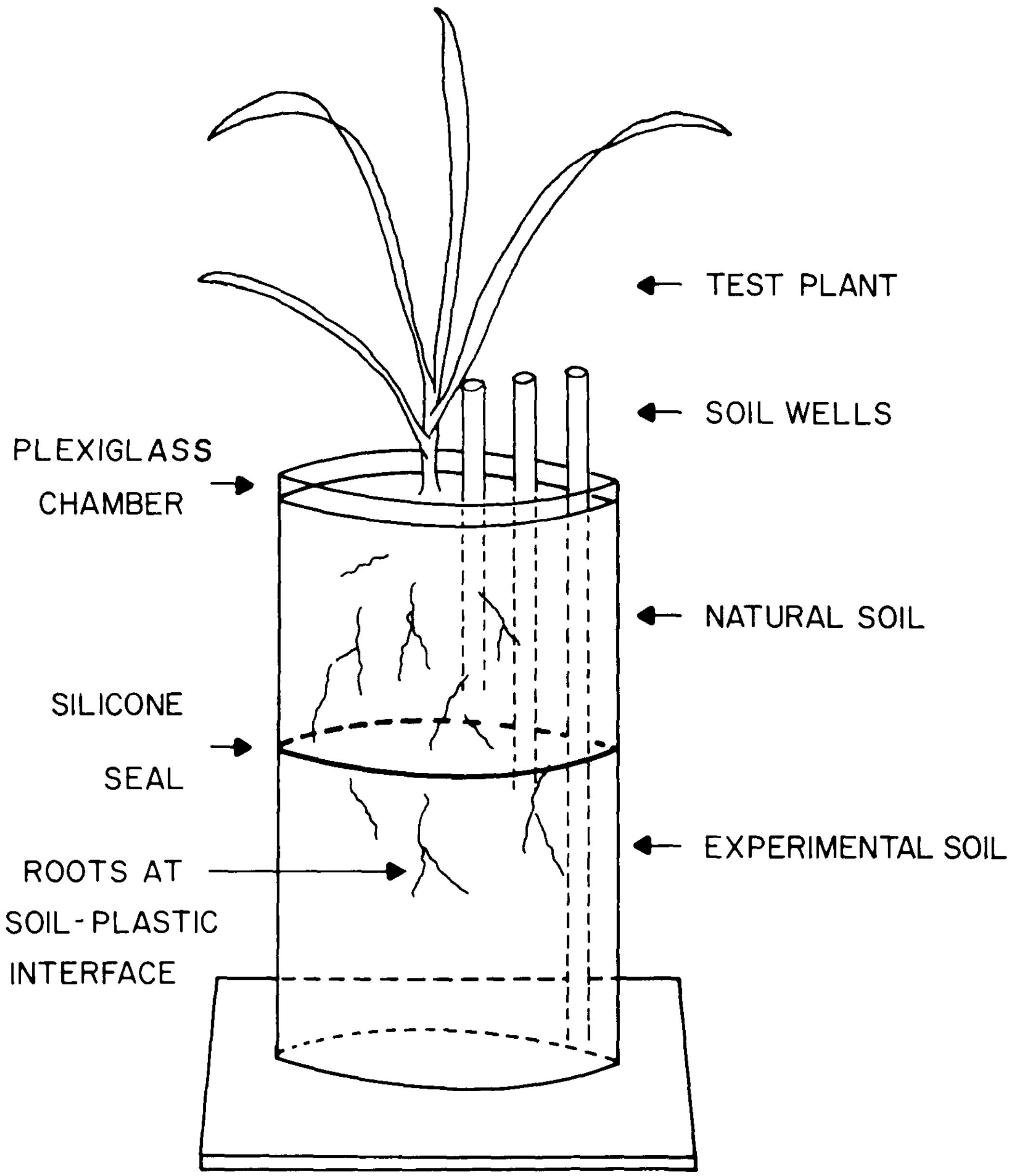

Figure 14

Root Growth Bioassay Chamber

filled with the root-free experimental soil, and the two were sealed together with silicone cement. The entire clear plexiglass chamber was covered with black cloth to retard the growth of algae. Soil wells were placed to extend into the center of the natural soil and into the top and bottom of the experimental soil. Water samples could thus be withdrawn from the natural and experimental soils and various treatments administered to the experimental soils through the tubes extending to that layer. Following an incubation period in a growth chamber under controlled temperature and light conditions, the bioassay chambers were dismantled and aerial biomass determined by harvesting the aboveground material, separating it into living and dead tissue, and drying it at 60°C before weighing. The natural and experimental soil chambers were separated, and after the underground macro-organic matter was washed free of the substrate on a 1-mm sieve, it was dried at 60°C and weighed. Three experiments were performed using these chambers.

Experiment 1

The objective of the first experiment was to test root growth of *S. alterniflora* and *S. patens* (two species to be planted on the Bolivar Peninsula marsh-creation site) to a set of environmental conditions. The experimental design was a complete randomized block with the 2 species, 2 salinities, 2 drainage conditions, 2 temperature regimes, and 4 replications. The natural cores were collected from a Sapelo Island, Georgia, marsh and placed over a sandy dredged material collected from Bolivar Peninsula near Galveston, Texas. The two salinities were 10‰ and 20‰ while the drainage conditions were saturated soil and field capacity.

The above soil condition was maintained by changing the water once per week in the experimental soil. In the saturated treatment the water level was maintained at the top of the experimental chamber. In the drained treatment, the water level was maintained at the bottom of the deepest well.

The winter and summer temperatures and day length regimes were means taken from the meteorological data for Galveston. In the winter the temperature was 16°C during the 12-hr day and 9°C during the 12-hr night. Summer conditions were 32°C during the 14-hr day and 26°C during the 10-hr night. Maximum light intensity in the growth chamber was 5000 fc,* half of which was turned on during the hour after sunrise and off an hour prior to sunset.

After an incubation period from 14 November 1975 until 15 January 1976, the experiment was terminated.

Experiment 2

The objective of this study was to compare root growth of *S. alterniflora* and *S. patens* in natural soil and in three very different types of dredged material from Georgia. Two temperature regimes were tested to observe plant responses to seasonal variations. This experiment was designed around a complete randomized block using the 2 species, 4 substrates, 2 temperature regimes, and 8 replicates. The four substrates used were the natural soil from Sapelo Island, sand from Buttermilk Sound, sand with lenses of clay from the Darien River, and silt and clay from Jekyll Island. Since the temperature and light

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* Multiply footcandles by 10.76391 to obtain lumens per square meter.

regimes in Galveston, Texas, are similar to those in Georgia, the same conditions were used as in the previous study. This assay was incubated from 30 January 1976 until 31 March 1976.

Experiment 3

This study was designed to simulate conditions which would occur if the dredged material was deposited above the tidal influence or was deposited in a freshwater area adjacent to the natural saline environment. The study was done with freshwater plants (*Eleocharis obtusa*) using 5 types of dredged material and natural freshwater pond mud at the warm temperature regime previously used. The types of dredged material were Galveston area sand (saline); Georgia sand (brackish); Georgia sand and clay (brackish); Georgia silt and clay (saline); and a James River, Va., silt and clay (fresh). The substrates were watered only with fresh water. The incubation period was from 14 April to 15 June 1976.

Experiment 4

As a result of the response of *S. alterniflora* and *S. patens* root growth to temperature in experiments 1 and 2, experiment 4 was designed. The objective was to determine if the root growth was due to root temperatures alone, shoot temperatures alone, or a whole plant response. This study was conducted using chambers which allowed the roots of *S. alterniflora*, *Spartina bakeri*, and *S. patens* to be maintained at a temperature different than the shoots. Each test unit consisted of a core of natural plant stand 6.8 cm in diameter and 15 cm in length placed in the center of a square plastic tub 20 cm on a side with the space around the core filled with root-free soil from the natural plant stand. The water table in the *S. alterniflora* tubs was kept 5 cm below the surface while that for *S. patens* was held at 10 cm. The soil in the *S. bakeri* test units was kept moist but no free water table was maintained. These conditions approximated the natural field conditions.

Eight test units were prepared for each species. Four of each were placed in a randomized block design in a growth chamber where environmental conditions were those used to simulate summer in the earlier studies. In a second chamber, identical tubs and environmental conditions were established except that the soil temperature was held at 19°C by a refrigerated water bath. After the growth period of 12 weeks the original cores were removed from the center of the tubs and the new growth in the surrounding soil, both aerial and underground, was harvested. Roots and rhizomes were separated and all parts dried at 60°C.

Results and Discussion

Experiment 1

No significant differences were observed in the root growth of *S. alterniflora* under summer and winter conditions (Table 36). In contrast, root growth of *S. patens* was significantly higher under winter conditions. These data indicate that when *S. patens* is used for marsh-creation projects in the southeast, fall is the optimum planting time. The growth pattern of S. patens appears to favor resource allocation to the roots and thus increases substrate stabilization.

Experiment 2

Root growth in natural soils of S. patens was greater under winter conditions while S. alterniflora exhibited greater growth under summer conditions (Table 36). Plant growth on the three types of dredged material did not differ significantly from each other but was much lower than in the natural soil.

Experiment 3

The results of the experiment with the five types of dredged material and the freshwater pond mud are shown in Table 37. Root growth fell into the following three groups: 1) greatest on Georgia sand; 2) intermediate on pond mud and James River mud; and 3) least on Galveston sand, silt and clay, and sand and silt. The relatively greater growth on Georgia sand can be explained by the initial low salinity of the substrate (1‰) and the fact that the salts were easily leached. The relatively lower growth in the two freshwater muds may have been caused by high sulfide concentrations in the substrates. Although sulfide concentrations were not measured, it was apparent by the odor of the substrate that free sulfides were present. The sulfides in the freshwater muds may have been toxic to root growth. The reduced root growth obtained in Galveston sand, silt and clay, and sand and silt was caused by the higher salt content of these substrates.

Table 36

Underground Biomass (mg) of Plants Grown in Bioassay Units with Several Substrate and Temperature Regimes

Treatment	*S. alterniflora* Summer	*S. alterniflora* Winter	*S. patens* Summer	*S. patens* Winter	$\bar{X}$
Experiment 1					
Galveston sand					
10 ‰					
saturated	130	99	28	164	139
drained	148	106	73	248	144
20 ‰					
saturated	158	146	7	238	137
drained	67	164	30	272	133
$\bar{X}$	126	129	34	230	
Experiment 2					
natural soil	630	50	100	620	
silt and clay	80	NT	NT	80	
sand	80	NT	NT	90	
sand and clay	50	NT	NT	70	

NT - not tested.

Table 37

Underground Biomass of *Eleocharis obtusa* Grown in Bioassay Units with Various Substrates in the Test Chambers

Experimental Substrate	Biomass (mg)
Pond mud	144
James River mud	138
Georgia sand	392
Galveston sand	57
Silt and clay	60
Sand and clay	78

Experiment 4

The results of this experiment are shown in Table 38. The two-way analysis of variance (ANOVA) revealed a significant temperature species interaction. Hence a series of one-way ANOVA tests were performed. Root growth in the warm soil was greater in all species (α = 0.1, S. alterniflora; α = 0.02, S. bakeri; α = 0.05, S. patens). Rhizome growth in S. bakeri was greater than the other two species at the warm temperature (α = 0.07). Total underground production was higher for all species at the higher soil temperature (α = 0.10, S. alterniflora; α = 0.01, S. bakeri; α = 0.05, S patens).

Aerial biomass associated with the original core and initially root-free soil outside the core area is shown in Table 39. The response of the three species was similar. The warm treatment resulted in significantly greater biomass (α = 0.01) for all three species. The Q_{10}* for S. alterniflora, S. bakeri, and S. patens was 2.00, 1.90, and 2.54, respectively. In the case of the root systems, all three species showed a positive response to warm temperature with the response of S. bakeri and S. patens being much greater than that of S. alterniflora (Figure 15 and Table 38). The data from this experiment indicate the differences in root growth seen in the earlier experiments were the results of the effect of temperature on the shoots or the combination of shoots and the root system rather than just the direct effect on the roots.

A two-way ANOVA showed no significant interaction, thus the three species behaved the same to the temperature differential. The effect

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* Q_{10} = factor by which respiration changes for every 10°C change in temperature.

Table 38

Root and Rhizome Growth (mg dry weight) of Three Species of Spartina Grown Under Two Temperature Regimes

Species	Warm			Cool		
	Roots	Rhizomes	Total	Roots	Rhizomes	Total
S. alterniflora	1430	400	1830	890	140	1030
S. bakeri	9880	1480	11350	4250	620	4870
S. patens	2480	110	2590	990	200	1190

Table 39

Aerial Biomass (mg dry weight) of Three Species of *Spartina* Grown Under Two Temperature Regimes

Species	Warm		Cool	
	In core	Out of core	In core	Out of core
S. alterniflora	6950	0	3910	0
S. bakeri	17180	1510	10040	0
S. patens	9440	130	4340	0

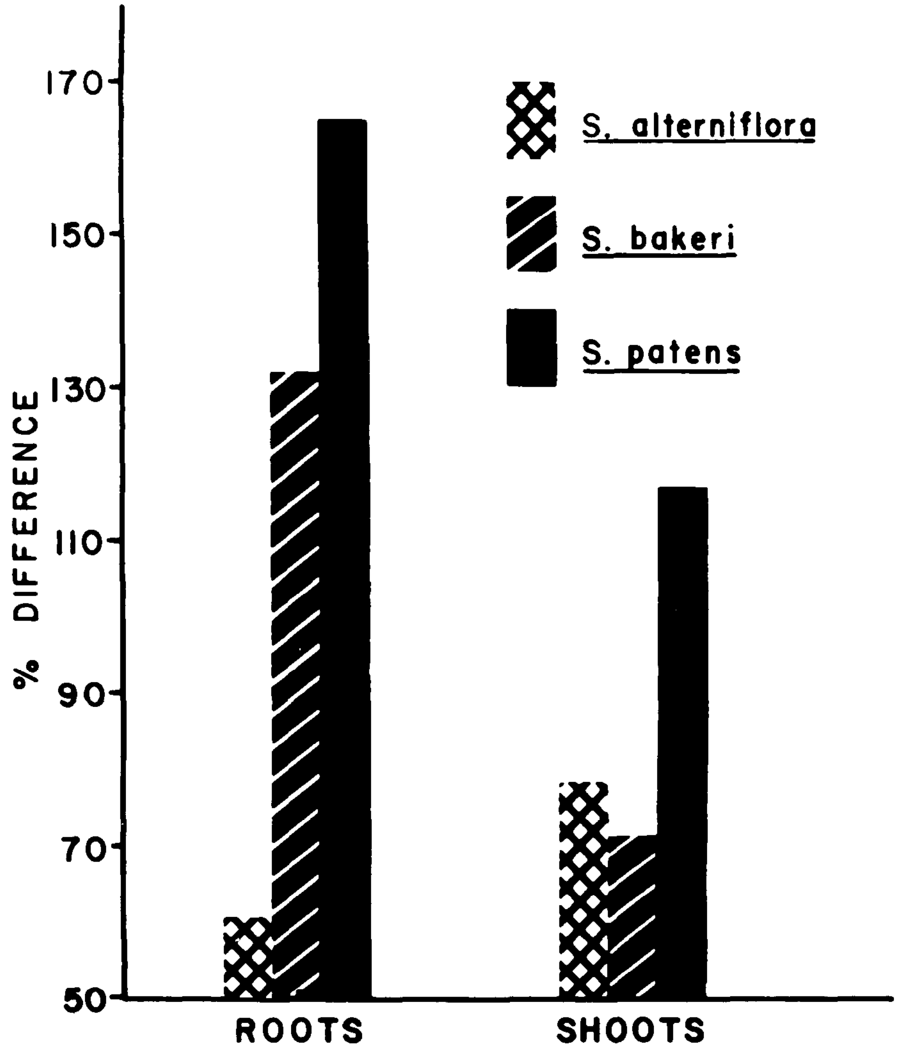

Figure 15

Response of Roots out of Core and Shoots in Core to Temperature
Expressed as % Difference in Total Biomass
When Grown in the Warmer Environment

of cool root temperatures may have reduced shoot growth in a number of ways. Net CO_2 assimilation by a variety of plants has been shown to be regulated by root temperature (Brouwer, 1963). The shape of the response curves in many studies indicates the root temperature is limiting only at the extremes. It is not likely that the temperatures used in the experiment (19 and 27°C) were at the extremes for these _Spartina_ species. Other possible effects of temperature could have been on water or nutrient absorption and movement (Takeshima, 1964). The temperature differential may also have affected the allocation of photosynthate.

Summary

In a test with a freshwater plant (_Eleocharis obtusa_) and five dredged material types, root growth was greatest in a sandy dredged material of low salinity. Approximately 1/3 as much growth occurred in two freshwater muds. Growth in a saline sand, a saline silty clay, and a brackish mixture of sand and clay produced only 1/7 the growth obtained with low salinity sand.

S. patens root growth was increased when the whole plant was grown under cooler rather than warmer environmental conditions. _S. patens_ and _S. alterniflora_ root growth did not differ under drained or saturated conditions when a sand substrate was used. Equal growth was obtained with either 10 or 20‰ salinity. Growth in natural soil was 6-12 times greater than in the various types of dredged material tested. When the soil temperature alone was reduced, three species of _Spartina_ (_S. alterniflora_, _S. bakeri_, and _S. patens_) all showed reduced

aerial and underground growth. This indicates that the increased root growth at low temperatures seen in two earlier experiments where whole plants were studied was either a whole plant effect or an effect on the shoots alone, not simply a direct effect on the root systems.

PART VII: CONCLUSIONS AND RECOMMENDATIONS

A study was made of the dynamics of the underground portion of some salt marsh plants along the western coast of the Atlantic Ocean. The soils supporting those plants were characterized and experiments were conducted on the substrate selective properties of the plants. Conclusions resulting from the study are as follows:

1. Three types of underground macro-organic matter profiles were found for the series of plants and sites studied.
   a. Type 1, uniform with depth (Creekbank *S. alterniflora*-GA; Creekbank *S. alterniflora*-ME).
   b. Type 2, decreases with depth (*B. frutescens*-GA; *D. spicata*-GA; *J. gerardi*-DL,ME; *J. roemerianus*-GA; *S. virginica*-GA, DL; *S. cynosuroides*-GA; High marsh *S. alterniflora*-GA; *S. patens*-GA,DL,ME; *S. virginicus*-GA).
   c. Type 3, at first increasing with depth and then decreasing as with Type 2 (*D. spicata*-DL; *P. communis*; Creekbank *S. alterniflora*-ME).
2. Annual increments were calculated as a minimum estimate of production.
   a. Underground production usually equalled or exceeded reported aerial productivity estimates.
   b. In the case of *S. patens*, *S. virginica*, and *D. spicata*, underground production increased with latitude.
   c. The annual increment for *S. virginica* and *D. spicata* was

greater in Delaware than Georgia, but the turnover times were similar.

d. The mean production for the 18 stands sampled was 654 g/m^2 (range 1686-80) while the mean turnover time was 57 months (range 224-18.4).

3. The macro nutrient content (N, P, K) of the MOM decreased with depth. Since no similar pattern was observed with carbon, the C:N ratio decreased with depth. This deeper material probably decays very slowly because of its composition and the anaerobic environment under which it grows.

4. Most of the marsh soils studied could be categorized as Sulfaquests. The chemical and physical characteristics described will extend the small data base available on marsh soils in Georgia, Delaware, and Maine.

5. Water movement through 13 marsh soils in Georgia, Delaware, and Maine appears to be rather slow in view of the long retention of extractable rhodamine WT when a pulse of dye was injected into the soil.

6. A variety of responses to a nitrogen pulse were observed.

   a. A positive response in biomass was obtained with _S. virginica_ and high marsh _S. alterniflora_ in Georgia, as well as _J. gerardi_ and _S. virginica_ in Delaware.

   b. Although _S. virginicus_ in Georgia did not respond with an increase in biomass, the nitrogen content increased. An increase in chlorophyll was noted in _B. frutescens_ in Georgia and *D. spicata* in Delaware. No responses to nitrogen were detected in the Maine samples.

7. Several methods of assessing marsh plant growth on dredged material were evaluated. They varied from a method used in growth chambers to one used on-site in the field. The growth chamber method proved especially useful in testing one or two variables on root growth in a dredged material. An intermediate method designed for greenhouse use appeared to be least useful since it had the disadvantage of the artificial nature of the studies out of the field without the completely controlled conditions achieved in the growth chamber. The most useful method for examining the practical problems faced in trying to vegetate dredged material was the field bioassay. Although the environmental conditions in the field are not always known, they do represent the combination of factors to which the plants will be exposed. Some of the differences between growth chamber, greenhouse, and field studies were predicted based on soil tests and pH, but other factors such as the leaching of clay from the top layers by rainfall and percolating tidal water were not. Results such as these emphasized the need for a bioassay technique which could be used to test specific plant responses to specific dredged material under specific environmental conditions.

Recommendations as to the use of the material contained in this report are as follows:

1. Information contained in Parts II and III characterizes the natural marsh root system dynamics and soil conditions in Georgia, Delaware, and Maine. This information can be used to aid in determining:

   a. which marsh plants will be likely to do well on various kinds of dredged material, and

   b. when natural marsh conditions have been achieved in marshes developed on dredged material.

2. It is suggested that, as more data are collected on dredged material considered potential soil for growing marsh plants, the general methods of soil analysis described in this report be used. In this way a large set of data can be accumulated which will allow marsh ecologists to do the same kinds of correlations between soil tests and plant growth that agricultural researchers have done for years. In the soils examined, the most useful combinations of parameters in predicting marsh plant success were:

   a. soil texture,

   b. pH properties (pH in situ, pH in water, and pH in buffer),

   c. salinity (in situ, leachable, desalination index),

   d. total nitrogen (which can be obtained by correlation with carbon).

3. In the future, accurate prediction of plant performance may be made based on knowledge about all plant requirements and dredged material behavior under a variety of environmental conditions. A field bioassay prior to dredging is strongly recommended to aid in predicting the outcome of planting specific marsh plants on a specific dredged material under a specific set of environmental conditions.

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In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Gallagher, John L
Underground biomass dynamics and substrate selective properties of Atlantic coastal salt marsh plants / by John L. Gallagher, F. Gerald Plumley, Paul L. Wolf, The University of Georgia Marine Institute, Sapelo Island, Georgia. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1977.
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Appendixes A-C

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December 1977

APPENDIX A: UNDERGROUND BIOMASS

Table A1a

Underground Biomass Expressed in g/m^2 for Depth Zones in Stands of Marsh Plants in Delaware

Species	June, 1974			July and August, 1974		
	Depth (cm)	$\bar{X}$	CV	Depth (cm)	$\bar{X}$	CV
Distichlis spicata	0-5	1825	27.4	0-5	2490	14.8
	5-10	2712	16.4	5-10	2880	6.5
	10-15	2278	21.8	10-15	2527	54.5
	15-20	10[illegible]3	11.9	15-20	946	61.3
	20-35	1014	51.2	20-35	1164	40.7
Juncus gerardi	0-5	3498	55.6	0-5	2784	11.0
	5-10	801	36.3	5-10	1177	18.0
	10-15	466	19.0	10-15	869	53.2
	15-35	2278	68.7	15-35	1404	38.8
	35-55	1648	79.2	35-55	222	30.1
Phragmites communis *(between)	0-5	691	81.2	0-5	174	58.6
	5-10	1053	16.7	5-10	369	57.0
	10-15	1313	80.5	10-15	1064	23.7
	15-20	1438	137.0	15-20	521	60.9
	20-35	1845	89.4	20-35	899	27.6
	35-55	1483	1.1	35-55	346	36.0
	55-75	1324	105.2	55-75	181	57.2
Phragmites communis *(over)	0-5	838	38.6	0-5	958	72.7
	5-10	844	52.9	5-10	928	52.2
	10-15	792	80.5	10-15	1404	77.5
	15-20	867	50.6	15-20	1048	78.2
	20-35	1223	30.6	20-35	1320	69.3
	35-55	867	33.0	35-55	573	55.4
	55-75	1358	130.0	55-75	278	24.9
Salicornia virginica	0-5	1571	14.6	0-5	1653	17.6
	5-10	724	58.8	5-10	403	32.6
	10-15	367	22.4	10-15	168	42.2
	15-35	380	31.3	15-35	231	32.1

*Over-plant cores were taken with a stem centered in the core and between-plant cores without stems in the core.

$\bar{X}$ = Mean; CV = Coefficient of Variation.

Table A1b

Underground Biomass Expressed in g/m^2 for Depth Zones in Stands of Marsh Plants in Delaware

	September, 1974				November, 1974		
Species	Depth (cm)	$\bar{X}$	CV	Species	Depth (cm)	$\bar{X}$	CV
Phragmites communis *(between)	0-5	475	82.6	Distichlis spicata **	0-5	1750	29.2
	5-10	469	50.3		5-10	2520	34.0
	10-15	928	80.3		10-15	890	41.4
	15-20	935	61.8		15-20	537	41.0
	20-35	1886	16.2		20-35	528	31.6
	35-55	876	70.9				
	55-75	559	117.5				
Phragmites communis *(over)	0-5	709	27.2	Juncus gerardi **	0-5	2429	12.4
	5-10	980	7.1		5-10	928	17.1
	10-15	1601	5.4		10-15	686	16.6
	15-20	912	44.7		15-35	1472	9.6
	20-35	2053	7.3		35-55	537	16.0
	35-55	1388	109.9				
	55-75	980	109.4				
Salicornia virginica	0-5	1834	9.2		0-5	1616	8.8
	5-10	598	36.9		5-10	539	34.0
	10-15	308	36.6		10-15	321	13.5
	15-35	358	36.7		15-35	272	42.9
Spartina patens	0-5	2028	13.2		0-5	2327	15.6
	5-10	715	34.7		5-10	1277	42.5
	10-15	340	41.1		10-15	285	44.4
	15-35	457	45.1		15-35	353	31.6

*Over-plant cores were taken with a stem centered in the core and between-plant cores without stems in the core.

**Cores taken from other than original stand for comparative purposes.

$\bar{X}$ = Mean; CV = Coefficient of Variation.

Table A1c

Underground Biomass Expressed in g/m^2 for Depth Zones in Stands of Marsh Plants in Delaware

Species	Depth (cm)	$\overline{X}$	CV
	January, 1975		
Juncus gerardi	0-5	2554	27.0
	5-10	661	35.1
	10-15	412	29.9
	15-35	833	61.2
	35-55	326	25.4
Salicornia virginica	0-5	1739	10.1
	5-10	484	17.1
	10-15	226	15.8
	15-35	326	31.2
Spartina patens	0-5	2087	45.0
	5-10	675	40.4
	10-15	217	39.4
	15-35	217	24.0
	March, 1975		
Spartina patens	0-5	1888	16.8
	5-10	1236	49.3
	10-15	376	56.0
	15-35	254	47.9
	May, 1975		
Spartina patens	0-5	2133	31.2
	5-10	611	24.3
	10-15	340	61.5
	15-35	426	36.3

$\overline{X}$ = Mean; CV = Coefficient of Variation.

Table A2a

Underground Biomass Expressed in g/m^2 for Depth Zones in Stands of Marsh Plants in Georgia

Species	June, 1974 Depth (cm)	June, 1974 $\overline{X}$	June, 1974 CV	July and August, 1974 Depth (cm)	July and August, 1974 $\overline{X}$	July and August, 1974 CV
Borrichia frutescens	0-5	217	77.1	0-5	412	45.7
	5-10	525	90.3	5-10	620	48.9
	10-15	177	121.4	10-15	127	76.4
	15-35	45	61.0	15-35	91	43.2
Distichlis spicata	0-5	1757	31.7	0-5	2164	43.4
	5-10	611	102.4	5-10	738	23.5
	10-15	122	55.0	10-15	254	44.8
	15-35	566	85.4	15-35	489	67.0
Salicornia virginica	0-5	367	26.4	0-5	308	80.7
	5-10	430	66.2	5-10	344	70.8
	10-15	118	53.3	10-15	118	73.6
	15-35	[illegible]	[illegible]	15-35	118	65.8
Spartina cynosuroides *(between)	0-5	143	79.6	0-5	559	75.8
	5-10	143	79.8	5-10	152	56.4
	10-15	90	25.0	10-15	181	43.2
	15-35	974	39.1	15-35	1992	69.2
	35-55	980	26.8	35-55	1048	65.1
Spartina cynosuroides *(over)	0-5	498	65.5	0-5	1773	46.6
	5-10	844	62.1	5-10	2099	53.1
	10-15	1103	104.9	10-15	2536	58.5
	15-35	2959	71.7	15-35	1795	48.9
	35-55	2076	40.5	35-55	1336	72.0
Spartina patens	0-5	774	45.2	0-5	919	57.7
	5-10	294	48.6	5-10	312	47.1
	10-15	195	34.5	10-15	145	13.9
	15-35	244	40.0	15-35	240	29.7
Sporobolus virginicus	0-5	521	105.6	0-5	543	54.6
	5-10	118	25.0	5-10	177	89.5
	10-15	118	85.4	10-15	72	34.4
	15-35	389	65.8	15-35	208	84.7

*Over-plant cores were taken with a stem centered in the core and between-plant cores without stems in the core.

$\overline{X}$ = Mean; CV = Coefficient of Variation.

Table A2b

Underground Biomass Expressed in g/m^2 for Depth Zones in Stands of Marsh Plants in Georgia

September, 1974			
Species	Depth (cm)	$\bar{V}$	CV
Borrichia frutescens **	0-5	278	139.0
	5-10	174	27.0
	10-15	120	125.7
	15-35	68	88.0
Distichlis spicata **	0-5	582	37.4
	5-10	317	51.5
	10-15	165	39.6
	15-35	378	39.0
Spartina cynosuroides	0-5	113	20.0
	5-10	376	158.2
	10-15	505	110.2
	15-35	770	16.4
	35-55	2973	60.6
Spartina cynosuroides *(over)	0-5	1669	36.6
	5-10	2226	35.8
	10-15	2355	31.4
	15-35	[illegible]	[illegible]
	35-55	6482	[illegible]

November, 1974			
Species	Depth (cm)	$\bar{V}$	CV
Distichlis spicata	0-5	1766	11.0
	5-10	543	61.7
	10-15	317	86.9
	15-35	1012	53.0
	0-5	731	76.9
	5-10	210	53.0
	10-15	204	106.0
	15-35	333	23.9
Distichlis spicata **	0-5	754	16.6
	5-10	136	60.0
	10-15	61	21.5
	15-35	582	34.9
Salicornia virginica	0-5	408	57.7
	5-10	272	43.3
	10-15	158	111.6
	15-35	129	10.2
Salicornia virginica	0-5	657	62.9
	5-10	401	32.6
	10-15	165	55.3
	15-35	215	67.0
Salicornia virginica **	0-5	340	37.1
	5-10	23	0.0
	10-15	23	0.0
	15-35	16	82.9

(Continued)

Table A2b (Concluded)

Species	September, 1974 Depth (cm)	$\bar{V}$	CV	Species	November, 1974 Depth (cm)	$\bar{V}$	CV
Sporobolus virginicus	0-5	616	22.7		0-5	641	32.0
	5-10	294	36.1		5-10	226	34.6
	10-15	158	66.3		10-15	91	66.0
	15-35	638	38.2		15-35	641	60.8
				Sporobolus virginicus **	0-5	482	42.6
					5-10	84	56.2
					10-15	52	100.4
					15-35	226	155.9
				Sporobolus virginicus **	0-5	378	22.7
					5-10	45	50.0
					10-15	23	0.0
					15-35	23	0.0

**Cores taken from other than original stand for comparative purposes.

$\bar{X}$ = Mean; CV = Coefficient of Variation.

Table A2c

Underground Biomass Expressed in g/m^2 for Depth Zones in Stan[illegible] [illegible] in Georgia

	December, 1974				January, 1975		
Species	Depth (cm)	$\overline{V}$	CV	Species	Depth (cm)	$\overline{V}$	CV
Borrichia frutescens	0-5	131	132.1		0-5	136	76.3
	5-10	240	69.2		5-10	113	69.2
	10-15	63	30.0		10-15	91	43.2
	15-35	127	104.6		15-35	129	53.7
				Borrichia frutescens **	0-5	91	90.0
					5-10	106	24.5
					10-15	75	46.4
					15-35	106	117.2
Salicornia virginica	0-5	326	35.6		0-5	290	63.6
	5-10	217	59.2		5-10	267	22.0
	10-15	91	84.8		10-15	122	67.6
	15-35	68	57.7		15-35	122	59.4
				Spartina cynosuroides *(between)	0-5	152	94.8
					5-10	346	111.4
					10-15	220	145.9
					15-35	1229	139.9
					35-55	3570	38.6
				Spartina cynosuroides *(over)	0-5	446	46.0
					5-10	355	37.3
					10-15	718	76.1
					15-35	1895	31.2
					35-55	3978	82.7
				Spartina patens	0-5	1080	24.5
					5-10	249	9.1
					10-15	143	24.3
					15-35	181	37.5
				Spartina patens **	0-5	181	21.6
					5-10	120	28.9
					10-15	52	50.0
					15-35	272	25.0

*Over-plant cores were taken with a stem centered in the core and between-plant cores without stems in the core.

**Cores taken from different stands for comparative purposes.

$\overline{X}$ = Mean; CV = Coefficient of Variation.

Table A3a

Underground Biomass Expressed in g/m^2 for Depth Zones in Stands of Marsh Plants in Maine

Species	June, 1974 Depth (cm)	June, 1974 $\overline{X}$	June, 1974 CV	July and August, 1974 Depth (cm)	July and August, 1974 $\overline{X}$	July and August, 1974 CV	September, 1974 Depth (cm)	September, 1974 $\overline{X}$	September, 1974 CV
Carex paleacea	0-5	1886	37.7	0-5	2318	35.6	0-5	2472	26.6
	5-10	2056	18.5	5-10	2803	19.4	5-10	2930	17.9
	10-15	1852	24.1	10-15	2151	70.9	10-15	2594	15.9
	15-35	6416	27.1	15-35	6353	42.0	15-35	7666	3.1
	35-55	4084	39.2	35-55	5311	37.8	35-55	5588	42.0
Jun[illegible] ger[illegible]	0-5	1942	28.0	0-5	1721	48.1	0-5	2798	17.1
	5-10	1897	57.8	5-10	1234	33.8	5-10	1064	11.6
	10-15	2355	26.9	10-15	1381	24.0	10-15	901	26.4
	15-35	4206	59.2	15-35	5221	74.2	15-35	2087	93.0
Spa[illegible]a alt[illegible]flora (cr[illegible]ank)	0-5	1970	42.9	0-5	2169	23.0	0-5	1752	46.0
	5-10	2921	3.3	5-10	2780	25.7	5-10	2594	11.6
	10-15	1780	17.9	10-15	1784	11.6	10-15	1616	6.9
	15-35	5307	78.3	15-35	7055	11.7	15-35	5981	16.0
Spartina alterniflora (High marsh)	0-5	1191	37.0	0-5	937	16.4	0-5	896	27.0
	5-10	878	38.8	5-10	833	14.3	5-10	865	29.7
	10-15	367	35.5	10-15	566	24.6	10-15	340	22.6
	15-35	1358	56.9	15-35	1693	46.8	15-35	1399	27.4
	35-55	919	99.0	35-55	910	135.2	35-55	1653	47.9
Spartina patens	0-5	1227	16.1	0-5	1236	10.2	0-5	1739	22.3
	5-10	1621	10.8	5-10	1494	22.9	5-10	1168	55.5
	10-15	1793	20.4	10-15	1390	33.2	10-15	1404	30.7
	15-35	3844	14.6	15-35	3663	17.8	15-35	4057	31.1
	35-55	3518	24.0	35-55	2106	13.9	35-55	2404	25.7

$\overline{X}$ = Mean; CV = Coefficient of Variation.

Table A3b

Underground Biomass Expressed in g/m^2 for Depth Zones in Stands of Marsh Plants in Maine

Species	Depth (cm)	$\overline{X}$	CV
	April, 1975		
Juncus gerardi	0-5	1856	35.0
	5-10	1277	15.2
	10-15	1413	65.6
Spartina alterniflora (creekbank)	0-5	1884	18.6
	5-10	2201	11.9
	10-15	1584	15.0
	15-35	5452	15.3
Spartina alterniflora (high marsh)	0-5	992	9.8
	5-10	1114	49.0
	10-15	466	26.3
	15-35	2155	35.6
	35-55	1204	78.3
Spartina patens	0-5	1361	28.9
	5-10	1186	21.4
	10-15	1019	6.5
	May, 1975		
Spartina patens	0-5	1449	20.4
	5-10	1182	12.2
	10-15	1376	10.6
	15-35	4098	14.6
	35-55	2431	32.3

$\overline{X}$ = Mean; CV = Coefficient of Variation.

APPENDIX B: MINERAL COMPOSITION OF UNDERGROUND MACRO-ORGANIC MATTER

Table B1a

Mineral Composition of Underground Macro-Organic Matter

In a Stand of Borrichia frutescens In Georgia

Month	Depth (cm)	%					PPM		
		N	P	K	Ca	Mg	Mn	Cu	Zn
Feb.	0-35	0.78(0)*	0.19(.01)	1.39(.16)	0.16(.09)	0.26(.03)	74(4)	12(7)	29(0)
June	0-35	1.02(.10)	0.13(.01)	1.30(.06)	0.34(.08)	0.30(.01)	59(6)	15(3)	52(6)

* Numbers in parentheses are standard errors.
(n = 5).

Table B1b

Mineral Composition of Underground Macro-Organic Matter

In a Stand of *Distichlis spicata* in Georgia

Month	Depth (cm)	% N	% P	% K	% Ca	% Mg	PPM Mn	PPM Cu	PPM Zn
Feb.	0-5	1.25(.08)	0.10(.17)	0.40(.05)	0.20(.07)	0.30(.02)	8(4)	14(2)	29(15)
	5-35	1.44(.05)	0.04(.01)	0.30(0)	0.30(.02)	0.30(.02)	2(1)	39(4)	21(4)
June	0-35	1.17(.12)	0.01(0)	0.02(.01)	0.20(0)	0.30(.01)	6(2)	25(6)	54(23)
Nov.	0-35	1.25(.05)	0.04( )	0.11(.05)	0.20(.05)	0.40(.01)	22(5)	22(4)	11(2)

* Numbers in parentheses are standard errors.
(n = 5).

Table B1c

Mineral Composition of Underground Macro-Organic Matter

In a Stand of Salicornia virginica in Georgia

Month	Depth (cm)	% N	% P	% K	% Ca	% Mg	PPM Mn	PPM Cu	PPM Zn
Feb.	0-35	1.21(.10)*	0.09(.01)	0.53(.07)	0.36(.10)	0.34(.02)	104(11)	3(1)	36(8)
June	0-35	(.08)	0.08(.01)	0.43(.05)	0.39(.06)	0.43(.03)	142(27)	7(2)	104(35)
Nov.	0-35	(.07)	0.10(.02)	0.11(.08)	0.39(.06)	0.39(.03)	40(7)	5(0)	34(9)

* Numbers in parentheses are standard errors. (n = 5).

Table B1d

Mineral Composition of Underground Macro-Organic Matter

In a Stand of *Spartina cynosuroides* in Georgia

Month	Depth (cm)	% N	% P	% K	% Ca	% Mg	PPM Mn	PPM Cu	PPM Zn
Feb.	0-15	0.92(.03)*	0.11(0)	0.33(.06)	0.60(.14)	0.17(.03)	382(123)	5(1)	22(8)
	15-45	1.02(.03)	0.11(.02)	0.28(.06)	0.65(.10)	0.16(.02)	262(51)	3(1)	48(17)
June	0-15	0.99(.08)	0.17(.02)	0.49(.15)	0.40(.16)	0.17(.01)	229(57)	7(1)	41(15)
	15-55	0.78(.03)	0.11(.02)	0.30(.08)	0.69(.21)	0.16(.01)	237(31)	7(2)	33(11)

* Numbers in parentheses are standard errors.
(n = 5).

Table B1e

Mineral Composition of Underground Macro-Organic Matter

in a Stand of Spartina patens in Georgia

Month	Depth (cm)	%					PPM		
		N	P	K	Ca	Mg	Mn	Cu	Zn
Feb.	0-35	0.82(.05)*	0.12(.04)	0.27(.14)	.44(.17)	0.23(.17)	52(10)	5(3)	129(85)
June	0-35	0.81(.04)	0.13(.02)	0.34(.05)	24(.02)	0.22(.01)	51(2)	5(0)	106(10)

* Numbers in parentheses are standard errors.
(n = 5).

Table B1f

Mineral Composition of Underground Macro-Organic Matter

In a Stand of Sporobolus virginicus in Georgia

Month	Depth (cm)	%					PPM		
		N	P	K	Ca	Mg	Mn	Cu	Zn
Feb.	0-35	0.86(.03)*	0.08(.01)	0.31(.03)	0.39(.02)	0.24(.02)	39(13)	7(3)	58(19)
June	0-35	0.94(1.0)	0.04(.01)	0.17(.06)	0.36(.07)	0.28(.02)	27(4)	10(4)	125(24)
Nov.	0-35	0.81(.11)	0.05(.01)	0.10(.09)	0.21(.06)	0.23(.04)	31(1)	6(0)	19(2)

* Numbers in parentheses are standard errors.
(n = 5).

Table B2a

Mineral Composition of Underground Macro-Organic Matter

In a Stand of Distichlis spicata in Delaware

Month	Depth (cm)	%					PPM		
		N	P	K	Ca	Mg	Mn	Cu	Zn
Feb.	0-5	1.39(.04)*	0.13(.02)	0.35(.09)	0.31(.14)	0.26(.04)	20(10)	17(7)	179(33)
	5-10	1.18(.09)	0.08(.03)	0.34(.09)	0.26(.03)	0.32(.02)	20(4)	20(9)	140(122)
	10-15	1.00(.16)	0.03(.03)	0.19(.10)	0.21(.03)	0.28(.07)	9(4)	16(9)	36(16)
	15-35	0.9[illegible]04)	0.01(.01)	0.08(.14)	0.22(.08	0.22(.05)	20(4)	5(4)	45(32)
June	0-5	1.3[illegible]1)	0.15(.07)	0.33(.05)	0.20(.04)	0.25(.06)	31(7)	13(4)	159(66)
	5-10	1.[illegible]1)	0.10(.04)	0.25(.05)	0.24(.04)	0.32(.03)	32(3)	22(4)	64(14)
	10-15	1.[illegible]0)	0.08(.03)	0.20(.03)	0.34(.05)	0.33(.03)	29(2)	20(2)	40(14)
	15-35	0.[illegible]4)	0.02(.02)	0.08(.03)	0.24(.10)	0.19(.08)	14(8)	6(2)	39(14)
Nov.	0-5	1.4[illegible]7)	0.12(.06)	0.34(.17)	0.43(.13)	0.34(.08)	25(9)	17(9)	84(15)
	5-10	1.2[illegible]4)	0.06(.03)	0.25(.13)	0.35(.03)	0.39(.03)	16(5)	21(11)	26(12)
	10-15	1.0[illegible].24)	0.07(.02)	0.27(.10)	0.36(.04)	0.26(.04)	18(2)	18(6)	22(6)
	15-35	0.7[illegible].06)	0.08(.04)	0.15(.14)	0.31(.10)	0.23(.06)	27(16)	11(7)	24(13)

* Numbers in parentheses are standard errors.
(n = 5).

Table B2b

Mineral Composition of Underground Macro-Organic Matter

In a Stand of *Juncus gerardi* in Delaware

Month	Depth (cm)	% N	% P	% K	% Ca	% Mg	PPM Mn	PPM Cu	PPM Zn
Feb.	0-5	1.32(.04)*	0.20(.01)	0.50(.06)	0.4[illegible]05)	0.30(.01)	74(12)	4(0)	34(3)
	5-45	0.78(.03)	0.08(.01)	0.70(.05)	0.2[illegible]04)	0.20(.02)	41(6)	4(1)	36(11)
June	0-5	1.19(.06)	0.10(.01)	0.20(.04)	0.2[illegible]4)	0.20(.03)	175(43)	6(1)	62(14)
	5-15	0.58(.06)	0.05(.01)	0.40(.05)	0.1[illegible]2)	0.20(.01)	55(8)	2(1)	36(13)
	15-45	0.60(.05)	0.05(.01)	0.30(.05)	0.1[illegible]2)	0.15(.02)	28(5)	4(2)	21(4)
Nov.	0-5	1.48(.06)	0.10(.01)	0.50(.05)	0.4[illegible]1)	0.20(.03)	133(45)	6(2)	114(48)
	5-15	0.87(.06)	0.08(.01)	0.50(.01)	0.2[illegible]2)	0.20(.01)	33(2)	1(0)	39(10)
	15-55	0.60(.05)	0.07(.01)	0.70(.07)	0.1[illegible]4)	0.20(.02)	24(3)	1(0)	19(8)

* Numbers in parentheses are standard errors.
(n = 5).

Table B2c

Mineral Composition of Underground Macro-Organic Matter

In a Stand of Phragmites communis in Delaware

Month	Depth (cm)	% N	% P	% K	% Ca	% Mg	PPM Mn	PPM Cu	PPM Zn
Feb.	0-35	1.23(.05)*	0.06(.01)	0.26(.07)	0.27(.04)	0.17(.02)	34(6)	18(3)	65(4)
	35-71	0.93(.02)	0.05(.01)	0.0 (0)	0.24([illegible])	0.14(.01)	15(2)	18(2)	94(13)
June	0-10	1.09(.06)	0.09(.01)	0.41(.02)	0.06(	0.12(.02)	47(5)	10(5)	73(16)
	10-35	0.94(.10)	0.12(.02)	0.70(.18)	0.05(	0.11(.01)	22(3)	11(7)	35(8)
	35-75	0.68(.13)	0.07(.01)	0.21(.05)	0.15(	0.11(.01)	21(4)	23(5)	58(22)

* Numbers in parentheses are standard errors.
(n = 5).

Table B2d

<u>Mineral Composition of Underground Macro-Organic Matter</u>

<u>In a Stand of Salicornia virginica in Delaware</u>

Month	Depth (cm)	%					PPM		
		N	P	K	Ca	Mg	Mn	Cu	Zn
Feb.	0-5	1.86(0)*	0.19(.03)	0.53(.02)	0.41(.03)	0.42(.11)	64(8)	12(2)	128(67)
	5-35	1.46(.27)	0.11(.03)	0.44(.20)	0.23(.15)	0.33(.04)	66(14)	8(2)	71(45)
June	0-5	1.72(.09)	0.14(.01)	0.42(.03)	0.48(.03)	0.37(.02)	81(9)	11(1)	85(19)
	5-35	1.07(.12)	0.06(.01)	0.24(.03)	0.24(.04)	0.21(.01)	38(4)	9(2)	58(31)

* Numbers in parentheses are standard errors.
(n = 5).

Table B2e

Mineral Composition of Underground Macro-Organic Matter

in a Stand of *Spartina patens* in Delaware

Month	Depth (cm)	N	P	K	Ca	Mg	Mn	Cu	Zn
Sept.	0-5	0.93(.04)*	0.08(0)	0.42(.02)	0.20(.01)	0.12(.01)	27(2)	3(0)	9(6)
	5-35	0.51(.04)	0.06(.01)	0.38(.09)	0.13(.01)	0.08(.02)	16(3)	4(2)	48(25)

* Numbers in parentheses are standard errors.
(n = 5).

Table B3a

Mineral Composition of Underground Macro-Organic Matter

In a Stand of *Spartina alterniflora* in Maine

Month	Depth (cm)	% N	% P	% K	% Ca	% Mg	PPM Mn	PPM Cu	PPM Zn
June	0-5	1.23(.12)*	0.11(.02)	0.61(.14)	0.25(.06)	0.25(.02)	33(6)	5(1)	39(4)
	5-10	0.98(.06)	0.05([illegible]	0.12(.03)	0.17(.03)	0.20(.02)	22(4)	3(1)	29(7)
	10-15	1.06(.03)	0.07 [illegible]1)	0.29(.05)	0.26(.02)	0.26(.01)	22(2)	5(1)	41(6)
	15-31	0.81(.10)	0.05 [illegible])	0.09(.03)	0.25(.04)	0.20(.02)	49(5)	5(2)	37(10)

* Numbers in parentheses are standard errors.
(n = 5).

Table B3b

Mineral Composition of Underground Macro-Organic Matter

In a Stand of *Juncus gerardi* in Maine

Month	Depth (cm)	% N	% P	% K	% Ca	% Mg	PPM Mn	PPM Cu	PPM Zn
June	0-5	1.31(.03)*	0 [illegible](.01)	0.40(.08)	0.30(.02)	0.30(.02)	53(5)	4(1)	39(14)
	5-10	1.21(.02)	0 [illegible])	0.30(.06)	0.30(.03)	0.20(.01)	24(4)	5(1)	14(3)
	10-15	0.99(.44)	0 [illegible].01)	0.20(.05)	0.20(.05)	0.20(.02)	18(3)	5(2)	9(3)
	15-30	0.96(.08)	0 [illegible].01)	0.20(.03)	0.30(.04)	0.20(.03)	38(4)	6(2)	25(5)

* Numbers in parentheses are standard errors.
(n = 5).

Table B3c

Mineral Composition of Underground Macro-Organic Matter

In a Stand of *Spartina patens* In Maine

Month	Depth (cm)	% N	% P	% K	% Ca	% Mg	PPM Mn	PPM Cu	PPM Zn
June	0-5	1.50(.14)*	0.13(.02)	0.38(.04)	0.31(.08)	0.24(.02)	37(8)	8(4)	85(10)
	5-10	1.51(.01)	0.08(0)	0.17(.06)	0.34(.05)	0.28(.02)	25(3)	6(2)	29(7)
	10-15	1.45(.07)	0.05(0)	0.12(.03)	0.25(.03)	0.25(.03)	23(4)	4(2)	34(2)
	15-35	[illegible]12(.05)	0.06(.01)	0.15(.07)	0.30(.03)	0.24(.03)	34(9)	3(1)	52(22)
	35-53	[illegible]1(.02)	0.06(0)	0.17(.04)	0.31(.02)	0.23(.02)	28(3)	5(2)	58(14)

* Numbers in parentheses are standard errors. (n = 5).

APPENDIX C: SOIL PROFILE DESCRIPTIONS

Table C1

Soil Profile Description for Soils Supporting Tidal Marsh Plants in Georgia

Vegetation	Horizon depth (cm)	Color	Texture	Mottles	Structures & Consistency	Reaction	Boundary	Remarks
Borrichia frutescens	A1 0-4	Very dark gray 10YR 3/1	Sandy clay loam	Common fine faint dark gray	Massive, slightly sticky	pH 8.5	Clear wavy	*Borrichia* rhizomes, Fiddler Crab burrows, N-value <0.7
	C1g 4-28	Grayish brown 2.5Y 5/2	Sandy clay loam	Common medium faint olive gray 5Y 5/2	Massive, slightly sticky	pH 6.6	Gradual wavy	Few small ro[illegible], N-value <0.7
	C2g 28-64	Gray 5Y 6/1	Light sandy clay loam	Many coarse prominent very dark grayish brown 10YR 3/2	Massive, slightly sticky	pH 7.8	Gradual wavy	Few small r[illegible] small sand pockets, N-value <0.7
	C3g 64-125+	Gray 5Y 5/1 and dark gray 5Y 4/1	Sandy loam		Massive, non-sticky	pH 8.0		N-value <0.[illegible]
Distichlis spicata	A11 0-37	Black N 2/	Loam		Massive, slightly sticky	pH 8.8	Gradual wavy	Many small [illegible]-value <0.7
	A12 37-100	Black N 2/	Loam		Massive, slightly sticky	pH 8.4	Gradual wavy	Many small [illegible]-value <0.7
	C1g 100-150+	Very dark grayish brown 10YR 3/2	Sandy loam		Massive, non-sticky	pH 8.4		Few small ro[illegible]-value <0.7
Salicornia virginica	A1 0-7	Light brownish gray 2.5Y 6/2	Fine sand	Few fine prominent yellowish brown	Single grained, loose	pH 7.3	Gradual wavy	Few small, m[illegible] live fibrous roots, N-value <0.7
	C1g 7-32	Light brownish gray 10YR 6/2	Fine sand	Common medium prominent brown 10YR 5/3 and medium faint light gray 10YR 7/1	Single grained, loose	pH 7.4	Gradual wavy	N-value <0.7

(Continued)

Table C1 (Continued)

Vegetation	Horizon depth (cm)	Color	Texture	Mottles	Structures & Consistency	Reaction	Boundary	Remarks
Salicornia virginica	C2g 32-80	Light grey 10YR 6/1	Fine sand	Few large prominent yellowish brown 10YR 5/6	Single grained, loose	pH 7.6	Clear wavy	N-value <0.7
	C3g 80-150+	Greenish gray 5GY 5/1	Sandy clay loam	Few small pockets of gray (5Y 5/1) and dark grey (5Y 4/1) sandy loam and loamy sand	Massive, friable	pH 8.7		Few small dead fibrous roots, N-value <0.7
Spart. cynos.	A1 0-5	Brown to dark brown 10YR 4/3	Loamy sand	Common fine and medium distinct light brownish gray 2.5Y 6/2	Single grained, loose	pH 7.0	Abrupt smooth	Common fine grass roots and many large rhizomes
	C1g 5-20	Grayish brown 10YR 5/2	Sandy clay loam	Many fine distinct yellowish brown (10YR 5/6) and many fine faint gray (5Y 5/1)	Massive, friable	pH 7.0	Gradual wavy	Common small grass roots and few large rhizomes, common small sand pockets
	C2g 20-52	Gray to dark gray 5Y 5/1	Sandy clay loam	Common medium, prominent dark yellowish brown 10YR 3/4	Massive, friable	pH 7.1	Clear wavy	Common small grass roots, small sand pockets
	C3g 52-85	Dark gray N 4/	Silty clay loam		Massive, sticky	pH 7.0	Gradual wavy	N-value <0.7, about 40% decaying grass roots, stems, and leaves, giving the layer a putrid odor
	C4g 85-150	Dark gray 5GY 4/1	Loamy sand		Single grained, loose	pH 7.1		

(Continued)

Table C1 (Concluded)

Vegetation	Horizon depth (cm)	Color	Texture	Mottles	Structures & Consistency	Reaction	Boundary	Remarks
Spartina patens	A1 0-25	Very dark grey 10YR 3/1	Loamy sand	Few fine prominent dark brown mottles	Single grained, loose to very friable	pH 7.1	Clear wavy	Many small grass roots, N-value <0.7
	C1g 25-47	Dark grey 10YR 4/1	Sand	Few medium faint grey	Single grained, loose	pH 7.5	Clear wavy	Common small grass ro [illegible] -value <0.7, some uncoated sand grains
	C2 47-130	Dark reddish brown 10YR 3/1	Loamy sand		Massive, slightly compacted in place but very friable after removing	pH 7.2 Dry pH 7.8 Wet	Abrupt wavy	Slight odor of H_2S [illegible] edium grass roots, N-value <0.7
	C3g 130-160	Grey 5GY 6/1	Fine sand		Single grained, loose	pH 7.0		Few small grass root [illegible] e <0.7
Sporobolus virginicus	A11 0-3	Light gray 5Y 7/1 and gray 5Y 6/1	Sand		Single grained, loose	pH 6.8	Abrupt smooth	Many small grass roo [illegible] lue <0.7
	A12 3-13	Very dark gray 10YR 3/1 and black 10YR 2/1	Sand		Single grained, loose	pH 7.0	Clear wavy	Common small grass ro [illegible] value <0.7
	C1g 13-34	Gray 5YR 5/1 and light gray 5YR 6/1	Sand		Single grained, loose	pH 6.8	Gradual wavy	Few small grass roots [illegible] lue <0.7
	C2g 34-150+	Dark reddish brown 5YR 2/2	Sand		Massive, friable to loose	pH 7.3		Common medium grass roots, N-value <0.7

Table C2

Soil Profile Description for Soils Supporting Tidal Marsh Plants in Delaware

Vegetation	Horizon depth (cm)	Color	Texture	Structures & Consistency	Reaction	Remarks
Distichlis spicata	0-19	Dark gray	Silt loam		pH 6.7	Organic matter - mostly roots
	19-29	Gray	Sandy clay	Structureless; plastic and slightly sticky	pH 7.7	Many decomposed roots producing dark streaks; some lighter colored roots.
	29-45	Gray, brownish streaks	Sandy clay loam	Plastic-slightly sticky, some indication of weak structure	pH 7.8	
	45-75+	Mottled gray and yellow	Sandy clay loam	Slightly plastic, non-sticky	pH 7.2	
Salicornia virginica	0-8	Black top 1/2 cm, gray 1 cm, top grades to mottled gray/brown	Sandy loam	Slightly plastic, non-sticky	pH 7.5	Many fibrous roots; single grained
	8-53	Mottled gray red-brownish 50% (5YR)	Sandy loam		pH 7.8	Many disintegrated root channels; oxidized material appears to follow old root channels
	53-70	Gray w/some red-brown mottling (15-20%)	More clay (not great) sandy clay loam		pH 7.3	Less oxidation
	70+	Gray	Sand	Hard in place, loose when removed	pH 7.5	

(Continued)

Table C2 (Continued)

Vegetation	Horizon depth (cm)	Color	Texture	Structures & Consistency	Reaction	Remarks
Spartina patens and *Distichlis spicata* mixed	0-15	Gray-brown		Fibrous mass		Root area
	15-35	Gray	Silty clay loam	Structureless, slightly sticky, plastic		Ma[illegible]ous roots
	35-65	Dark gray black	Clay loam	Structureless, slightly sticky, plastic		M[illegible]s, more roots than laye[illegible] a[illegible] old earlier surface a[illegible]gain
	65-100+	Gray	Sandy loam	Massive, [illegible]ery plastic, slightl[illegible] [illegible]ticky		S[illegible]
Juncus gerardi	0-20	Gray	Sandy, clay	Structu[illegible]less, slightly sticky, [illegible]lightly plastic	pH 6.8	M[illegible]ous roots
	20-30	Gray, some red-brown mottling	Sandy clay loam	Weak s[illegible] angular, blocky struct[illegible]	pH 6.9	M[illegible]ous roots
	30-50	Yellowish-brown 10YR 56	Sandy clay loam	Weak medium, sub-angular blocky structure	pH 7.1	M[illegible]rous roots, no gray, b[illegible]rained
	50-80	Yellowish-brown (10YR) mottled w/some gray	Sandy clay	Weak angular blocky structure	pH 7.2	
	80-90		Sand			Grading to loose sand at 90 cm

(Continued)

Table C2 (Concluded)

Vegetation	Horizon depth (cm)	Color	Texture	Structures & Consistency	Remarks
Phragmites communis	0-25	Gray	S[illegible]ty clay [illegible]	Slightly sticky, slightly plastic, some angular structure	Root mass numerous
	25-75	Gray mottled w/some red brown	[illegible]dy clay [illegible]	Massive, structureless, slightly sticky, non-plastic	Still considerable roots throughout horizon
	75+	Gray	[illegible]dy clay [illegible]	Massive, slightly sticky, non-plastic	A few roots; root channel lined with brownish red

Table C3

Soil Profile Description for Soils Supporting Tidal Marsh Plants in Maine

Vegetation	Horizon depth (cm)	Color	Texture	Mottles	Structures & Consistency	Reaction	Boundary	Remarks
Carex paleacea	02 0-23	Gray 10YR 5/1	Mucky silt		Massive Slightly sticky, [illegible]	pH 6.4	Abrupt smooth	Many roots
	C1g 23-46	Gray 5Y 5/1	Silt		Massive Slightly sticky, [illegible]	pH 6.8	Abrupt smooth	No live roots, 50% by volume dead plant material
	C2g 46-71	Dark greenish gray 5GY 4/1	Silt		Massive Slightly sticky, [illegible]	pH 7.2	Abrupt smooth	30% by volume dead plant material, thin (<1/4") lens of sand and some bark
	C3g 71-96	Dark greenish gray 5GY 4/1	Silt		Massive Slightly sticky, [illegible]	pH 7.5		30% by volume dead plant material
Juncus gerardi	A11 0-3	L[illegible] gray/grey 5Y [illegible] with 3[illegible] [illegible]ack 10[illegible] [illegible] 5/1	Silt loam		Massive Firm, slightly sti[illegible] plastic	pH 7.0	Abrupt irregular	Many fine and medium roots
	A12 3-8	Very dark grey 10YR 3/1	Silt loam		Moderate very fine fine granular stru[illegible] Friable, slightly [illegible] plastic	pH 6.3	Abrupt smooth	High in organic matter Many fine and medium roots
	A13 8-15	Dark grey N4/	Silty clay loam	Common coarse prominent yellowish red 5YR 4/6	Moderate fine granu[illegible] structure along roots Firm, sticky, plastic	pH 6.2	Abrupt smooth	Many fine and medium roots

(Continued)

Table C3 (Continued)

Vegetation	Horizon depth (cm)	Color	Texture	Mottles	Structures & Consistency	Reaction	Boundary	Remarks
Juncus gerardi	A1h 15-25	Gray 5Y 5	Silt loam	Common coarse prominent yellowish red 5YR 5/6	Massive Firm, slightly sticky, plastic	pH 5.4	Abrupt smooth	Many med[illegible]m roots
	A21g 25-30	Gray 10YR	Silt loam	Common medium prominent brown to dark brown 7.5 YR 4/4	Massive Slightly sticky, plastic	pH 5.6	Abrupt smooth	Many me[illegible]m roots
	A22g 30-43	Greenish 5GY 6/1	Silt loam	Common fine prominent yellowish brown (10YR 5/6) along old root channels	Massive Firm, sticky, plastic	pH 5.0	Abrupt smooth	Few me[illegible] roots
	C1g 43-89	Greenish g[illegible] 5BG 5/1	Silty clay	Few fine prominent yellowish red (5 YR 5/8) along old root channels	Massive Firm, sticky, very plastic	pH 5.8	Abrupt smooth	Very few roots
	C2g 89-114	Greenish gray 5 BG 5/1 and olive 5Y 5/3	Silty clay		Weak fine and medium plates separating to moderate very fine angular blocks Firm, sticky, plastic	pH 6.5		No live roots, some fine dead roots along ped faces. Black (5YR 2/1). Stains in dendritic patterns on ped faces

(Continued)

Table C3 (Continued)

Vegetation	Depth (cm)	Color	Texture	Mottles	Structures & Consistency	Reaction	Boundary	Remarks
Spartina alterniflora (creekbank)	[illegible]	Olive gray 5Y 4/2	Silt loam		Massive Sticky	pH 6.6	Abrupt smooth	About 85% roots by volume
	[illegible]28	Very dark gray 5Y 3/1	Silt loam		Massive Sticky, plastic	pH 6.8	Abr[illegible] smooth	Layers of olive colored roots constituting 75% of volume
	28 41	Dark gray N 4/	Silt loam with globs of grey clay (N 5/)		Massive Very sticky, very plastic	pH 7.0	Ab[illegible] smooth	About 30% roots by volume
	IIC1g -91	Olive 5Y 4/4, 5/4	Silty clay		Moderate fine prisms separating to weak fine and medium plates and fine angular blocks Very sticky, very plastic	pH 7.4	Ab[illegible] smooth	Prism faces coated with green[illegible] gray (5BG 5/1). Some very dar[illegible] gray (N 3/). Stains on ped faces. Sand and pebbles mixed with clay (86-91)
	[illegible]							Bedrock
Spartina alterniflora (high marsh)	-1 [illegible]-15	Dark greenish gray 5GY 4/1	Silt		Massive Slightly sticky, plastic	pH 7.3	Abrupt smooth	Many roots
	15-25	Dark greenish gray 5GY 4/1	Silt		Massive Slightly sticky, plastic	pH 7.6	Abrupt smooth	Very few roots
	IIC26 25-61	Dark greenish grey 5GY 4/1			Massive Slightly sticky, plastic	pH 7.7	Abrupt smooth	Many dead straw colored root fragments. Two 3 cm layers of silt without dead plants
	IIIC28 61-94	Dark greenish grey 5GY 4/1	Silt		Massive Slightly sticky, plastic	pH 7.8		Few dead roots

(Continued)

Table C3 (Concluded)

Vegetation	Horizon depth (cm)	Color	Texture	Mottles	Structures & Consistency	Reaction	Boundary	Remarks
Sparting patens	A11 0-8	Dark gray 5Y 4/1	Silt		Massive Friable, slightly sticky, plastic	pH 6.8	Abrupt smooth	About 75% roots by [illegible]
	A12 8-15	Dark gray 10YR 4/1	Silt		Massive Friable, slightly sticky, plastic	pH 6.8	Abrupt smooth	About 95% roots by [illegible]
	A13 15-28	Dark gray 5Y 4/1	Silt		Massive Friable, slightly sticky, plastic	pH 6.7	Abrupt smooth	About 60% roots by [illegible]
	C1g 28-61	Greenish gray 5GY 5/1	Silt		Massive Firm, slightly sticky, plastic	pH 7.5	Abrupt smooth	No live roots, few [illegible] cts
	C2g 61-102	Greenish gray 5GY 5/1	Silt		Massive Firm, slightly sticky, plastic	pH 7.8		Consists of layers [illegible] and matted dead very pa[illegible]wn (10YR 7/4) plant mate[illegible]s. Silt layers are 10-1[illegible] thick and matted layers 3-5 cm thick